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# Hazardous Chemicals Handbook

Second edition

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# Preface to the second edition

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The aim of this book remains as for the first edition, namely to provide an initial point of ready reference for the identification of hazards and precautions for dangerous chemicals. It is targeted not only at those in the chemical and process industries, but also anyone likely to work with chemicals within industry and in the service sector, e.g. hospitals, universities, research laboratories, engineering, agriculture, etc. It embraces the entire life-cycle of chemicals during transport, storage, processing, marketing, use and eventual disposal and should appeal to chemists, occupational and environmental health practitioners and students, engineers, waste handlers, safety officers and representatives, and health care professionals. Clearly, more detailed texts or professional advice may need to be consulted for specific applications.

Since the first edition in 1994 there have been no significant changes in the fundamentals of chemistry, physics and toxicology upon which the safe handling of chemicals are based. There has, however, been some increase in knowledge relating to the chronic toxicological and potential environmental effects of specific chemicals, and in legislation and government guidelines. These are reflected in the second edition. In general, within the UK the predominant legislation relating to substances hazardous to health, the Control of Substances Hazardous to Health Regulations 1999 and its accompanying Approved Code of Practice, incorporate significant changes since the 1988 (and 1994) versions. There has been an increase in the controls applicable to the marketing and transportation of different classes of chemicals. Those applicable to major hazards have changed under the Control of Major Accident Hazard Regulations 1999. Other legislation has been introduced: e.g. the Confined Spaces Regulations 1997, the Reporting of Injuries, Diseases and Dangerous Occurrences Regulation 1995, the Health and Safety (Safety Signs and Signals) Regulations 1996, and the Pressure Systems Safety Regulations 2000 which is of importance to the scope of this text. Increased concern as to the possible environmental impacts of chemical discharges and disposal has been accompanied by more comprehensive legislation for control. General safety legislation was expanded by the introduction of various separate regulations in 1993, including that dealing with management of health and safety at work; workplace health, safety and welfare; workplace equipment; and personal protective equipment. These improvements are, in general, now reflected in industry.

The opportunity has been taken to improve each chapter and to update the information. The main changes include an expansion of the terminology in Chapter 2 and provision of an introduction to basic chemical principles for non-chemists in a new Chapter 3. Chapter 4 on Physicochemistry contains additional examples. Chapter 5 on Toxic chemicals has been enlarged and the table of hygiene standards updated. Chapters 6, 7 and 8 on Flammable chemicals, Reactive chemicals and Cryogenics, respectively, have been updated and expanded. The scope of Chapter 9 on Compressed gases has been widened to include additional examples together with the basic techniques of preparing gases *in situ*. Chapter 10 summarizes techniques for monitoring air quality and employee exposure. It has also been expanded to provide guidance on monitoring of water and land pollution.

The chapter on Radioactive chemicals (Chapter 11) has been updated. Considerations of safety in design (Chapter 12) are presented separately from systems of work requirements, i.e. Operating procedures (Chapter 13). The considerations for Marketing and transportation of hazardous chemicals are now addressed in two separate chapters (Chapters 14 and 15). Chemicals and the Environment are now also covered in two chapters (Chapters 16 and 17) to reflect the requirement that the impact of chemicals on the environment should be properly assessed, monitored and controlled. Although a substantial contribution to atmospheric pollution is made by emissions from road vehicles and other means of transport, and this is now strictly legislated for, this topic is outside the scope of this text. Chapter 18 provides useful conversion factors to help with the myriad of units used internationally.

Whilst the hazards identified, and the principles and practice for the control of risks are universal, i.e. they are independent of location, in order to assist quick-reference an appendix of relevant contemporaneous UK legislation has been added as a guide together with a much-expanded Bibliography in Chapter 19. Finally, for convenience of use, the Index has been enlarged.

It is hoped that the improvements will help to achieve the objectives for which the text was originally conceived, i.e. to summarize in relatively basic terms the hazards associated with chemicals and how the ensuing risks can be controlled, and to provide sufficient detailed information to supplement that obtainable from suppliers, government publications, trade associations, and computerized data banks where recourse to specialized textbooks may be premature, difficult or unnecessary.

P.A.C.  
C.J.M.

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# Preface to the first edition

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The aim of this handbook is to provide a source of rapid ready reference to help in the often complex task of handling, using and disposing of chemicals safely and with minimum risk to people's health or damage to facilities or to the environment.

The range of chemicals and chemical mixtures in common use in industry is wide: it is obviously impossible to list them all in a concise handbook, or to refer to all their proprietary names. The approach here has been to avoid 'random listing' and to arrange by type of hazard, dealing with the most widely used substances and those properties and characteristics of behaviour that are directly relevant to common use and to compliance with safety legislation. Numerous sources not restricted to those in the Bibliography were searched for information and although not listed, to achieve conciseness, these are acknowledged. The multiplicity of data sources also means that minor variations occur due to differences in the procedures and methods for their determination; however they provide general guidance. Whilst the data quoted in this text has been carefully collated, its accuracy cannot be warranted. For this reason, and to avoid overlooking consideration of other chemical-specific hazards or location-dependent legislation, it is advisable to refer to a Chemical Safety Data Sheet before using any chemical. These are readily available from suppliers (e.g. in the UK under S.6 of the Health & Safety at Work etc. Act 1974). For exhaustive treatment of physical, toxicological, flammable/explosive and reactive properties, and the background to – and limitations of – their determination or prediction, the reader is referred to standard textbooks (see Bibliography) such as:

*The Safe Handling of Chemicals in Industry* (Carson and Mumford)

*Dangerous Properties of Industrial Materials* (Sax and Lewis)

*Handbook of Reactive Chemical Hazards* (Bretherick)

*Handbook of Toxic and Hazardous Materials* (Sittig)

*Patty's Industrial Hygiene and Toxicology* (Clayton and Clayton)

The identification, assessment, control and monitoring of chemical-related hazards and environmental pollution control are, of course, required under a wide range of statutory legislation, dependent upon the country concerned. For example, in the UK the Health and Safety at Work etc. Act 1974, the Control of Substances Hazardous to Health Regulations 1988, the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972, the Control of Pollution Act 1974 and the Environmental Protection Act 1990 are supplemented by a wide variety of other measures. Legislative controls tend to change frequently and it is important to ensure that a check is made on current requirements and constraints in any specific situation involving chemicals.

It is hoped that this book will prove valuable to safety advisers, environmental health officers, emergency services personnel, safety representatives and those engaged in the transport or disposal of wastes – in fact, to anyone involved with chemicals 'in the field', i.e. away from ready access

to chemical safety data sheets, detailed texts, library facilities or computerized databanks. It also provides a useful summary for those who may need to make only passing reference to the hazardous properties and potential effects of chemicals, such as general engineering students and occupational health nurses.

P.A.C.  
C.J.M.

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# Introduction

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Industrial hazards cover a wide spectrum including fire and explosion, mechanical hazards (e.g. from moving machinery), electrical hazards, occupational exposures to ionizing and non-ionizing radiation, biological hazards (e.g. acute or chronic infections, parasitism, and toxic or allergic reactions to plant and animal matter), physical hazards (e.g. tripping, falling, impact from vehicles or falling objects) and ergonomical hazards (e.g. lifting or carrying heavy or awkward loads or from repetitive operations). Work-related stress can also lead to mental and physical ill-health. Different hazards may be associated with the manufacture, storage, transport, use, and disposal of chemicals. Environmental hazards, through persistent or accidental losses of chemicals, may also be related to these operations.

Working with pathogenic micro-organisms bears passing similarity to chemicals. Hence, in the UK micro-organisms are classified as *hazardous substances* under the Control of Substances Hazardous to Health Regulations and there is an accompanying Code of Practice. However, biological hazards arising from the working environment or from more specialized activities, e.g. working with pathogenic organisms in laboratories, are beyond the scope of this book. This text deals solely with occupational, industrial and environmental hazards associated only with chemicals. It includes fires and explosions since they inevitably involve chemical compounds.

Chemicals are ubiquitous as air, carbohydrates, enzymes, lipids, minerals, proteins, vitamins, water, and wood. Naturally occurring chemicals are supplemented by man-made substances. There are about 70 000 chemicals in use with another 500–1000 added each year. Their properties have been harnessed to enhance the quality of life, e.g. cosmetics, detergents, energy fuels, explosives, fertilizers, foods and drinks, glass, metals, paints, paper, pesticides, pharmaceuticals, plastics, rubber, solvents, textiles; thus chemicals are found in virtually all workplaces. Besides the benefits, chemicals also pose dangers to man and the environment. For example:

Of the many industrial fires in the UK in 1997 each of some 411 cost more than £50 000 with total losses amounting to £186m. These spanned a wide range of industrial and related premises as shown in Table 1.1. The most common sources of ignition (see Chapter 6) that year are shown in Table 1.2.

In the UK alone occupational health risks due to chemicals are illustrated by:

- 152 incidents in 1998 involving supply and use of flammable gas with around 70% causing carbon monoxide poisoning and 30 fires/explosions;
- 554 new cases of pneumoconiosis (excluding asbestosis) and 3423 assessed cases of bronchitis or emphysema (in coal miners) during the same period;
- annually there are 4500 cases of work-related skin disease (80% contact dermatitis), ca 1500 cases of occupational asthma (mainly from solder flux, isocyanates, wood dust, spray painting, metal treatment, plastics), ca 200 cases of allergic rhinitis;
- between 2% and 8% of all cancer deaths are of occupational origin;



**Table 1.1 Breakdown of U.K. fires causing more than £50 000 damage in 1997**

| <i>Occupancy</i>                             | <i>No. of fires</i> | <i>Loss £000</i> | <i>% of total cost of all fires</i> |
|----------------------------------------------|---------------------|------------------|-------------------------------------|
| Agriculture, forestry and fishing            | 27                  | 3282             | 2                                   |
| Paper, printing and publishing               | 14                  | 6480             | 3                                   |
| Food, drink and tobacco                      | 13                  | 7235             | 4                                   |
| Rubber and plastic                           | 7                   | 5371             | 3                                   |
| Textiles, footwear and clothing              | 7                   | 1894             | 1                                   |
| Timber and wood products excluding furniture | 6                   | 1042             | 1                                   |
| Chemicals and allied products                | 5                   | 4543             | 2                                   |
| Construction                                 | 5                   | 515              | —                                   |
| Metal manufacture                            | 4                   | 871              | —                                   |
| Engineering                                  | 4                   | 545              | —                                   |
| Other manufacturing industries               | 25                  | 20 249           | 11                                  |
| Retail distribution                          | 27                  | 15 021           | 8                                   |
| Transport and communications                 | 18                  | 13 390           | 7                                   |
| Wholesale distribution                       | 8                   | 26 250           | 14                                  |
| Education                                    | 39                  | 23 407           | 13                                  |
| Recreational/cultural                        | 30                  | 6946             | 4                                   |
| Clubs and public houses                      | 19                  | 4668             | 3                                   |
| Cafes/restaurants                            | 14                  | 2431             | 1                                   |
| Insurance, banking and business services     | 10                  | 1730             | 1                                   |
| Hotels/boarding houses                       | 6                   | 2516             | 1                                   |
| Hospitals                                    | 4                   | 925              | —                                   |
| Public admin./defence/law enforcement        | 3                   | 430              | —                                   |
| Hostels/holiday camps                        | 1                   | 99               | —                                   |
| Homes for disabled                           | 1                   | 100              | —                                   |
| Domestic dwellings                           | 63                  | 9970             | 5                                   |
| Other                                        | 26 434              | 518              | 14                                  |

**Table 1.2 Accidental fires (UK) in 1997: sources of ignition**

| <i>Ignition source</i>                                            | <i>No. of fires</i> | <i>% of all fires</i> | <i>Loss £000</i> | <i>% of total cost of all fires</i> |
|-------------------------------------------------------------------|---------------------|-----------------------|------------------|-------------------------------------|
| Electrical appliances                                             | 110                 | 26.8                  | 55 491           | 29.8                                |
| Smokers' materials                                                | 17                  | 4.1                   | 2138             | 1.1                                 |
| Gas appliances<br>(excluding blowlamps and welding)               | 10                  | 2.4                   | 2595             | 1.4                                 |
| Blowlamps: all fuels                                              | 7                   | 1.7                   | 2176             | 1.2                                 |
| Welding and cutting appliances                                    | 7                   | 1.7                   | 1340             | 0.7                                 |
| Oil and petroleum appliances<br>(excluding blowlamps and welding) | 6                   | 1.5                   | 714              | 0.4                                 |
| Unspecified appliances                                            | 5                   | 1.2                   | 578              | 0.3                                 |
| Rubbish burning                                                   | 4                   | 1                     | 417              | 0.2                                 |
| Chimney, stovepipe and flue                                       | 2                   | 0.5                   | 303              | 0.2                                 |
| Natural occurrence                                                | 2                   | 0.5                   | 215              | 0.3                                 |
| Ashes/soot                                                        | 1                   | 0.2                   | 50               | 0.1                                 |
| Other                                                             | 22                  | 5.4                   | 3789             | 2                                   |
| Total                                                             | 193                 | 47                    | 69 806           | 37.7                                |

- ca 1760 cases per year of acute poisonings and injuries from chemicals, the most common being from acids, caustic, and gases, with process operatives and tradesmen being at greatest risk;
- an estimated 9000 cases of sick building syndrome per year.

The UK Environment Agency deals with over 6000 oil pollution incidents each year. One estimate suggests that the chemical industry contributes to 50% of all air pollution with proportions approximating to sulphur dioxide (36%), carbon dioxide (28%), nitrogen oxides (18%), carbon monoxide (14%) and black smoke (10%). Motor spirit refining is responsible for ca 26% of emissions of volatile organic compounds to the atmosphere. In 1996 there were over 20 000 reports of water pollution incidents with 155 successful prosecutions.

The EC produces in excess of 2 billion tonnes of waste each year. 414 million tonnes arise in the UK and a further 68 million tonnes of hazardous waste are imported. All wastes must be disposed of safely.

Society must strike a balance between the benefits and risks of chemicals. In the workplace it is a management responsibility to ensure practices control the dangers, and it is for employees to collaborate in implementing the agreed procedures. Management must also prevent uncontrolled environmental releases and ensure all wastes are disposed of safely and with proper regard for their environmental impact. The aims of this book are to raise awareness and to help users identify, assess and control the hazards of chemicals to permit optimum exploitation whilst minimizing the dangers.

The hazards of 'chemicals' stem from their inherent flammable, explosive, toxic, carcinogenic, corrosive, radioactive or chemical-reactive properties. The effect of exposure on personnel may be acute, e.g. in a flash-fire or due to inhalation of a high concentration of an irritant vapour. Alternatively, prolonged or intermittent exposure may result in an occupational disease or systemic poisoning. Generally acute effects are readily attributable; chronic effects, especially if they follow a long latency period or involve some type of allergic reaction to a chemical, may be less easy to assign to particular occupational exposures. The possible permutations of effects can be very wide and exposure may be to a combination of hazards. For example, personnel exposed to a fire may be subject to flames, radiant heat, spilled liquid chemicals and vapours from them, leaking gases, and the pyrolytic and combustion products generated from chemical mixtures together with oxygen deficient atmospheres. However, whether a hazardous condition develops in any particular situation also depends upon the physical properties of the chemical (or mixture of chemicals), the scale involved, the circumstances of handling or use, e.g. the processes involved and degree of containment, and upon the control measures prevailing, e.g. provision of control and safety devices, local exhaust ventilation, general ventilation, personal protection, atmospheric monitoring and systems of work generally.

Hazard recognition and assessment always start from a knowledge of the individual properties of a chemical. What this may include is exemplified by Table 1.3. Additional properties, including those in Table 1.4, are relevant to environmental hazards, e.g. relating to behaviour on spillage or emission, and determination of permissible levels for disposal to air, land or water systems. Other properties may be relevant, e.g. odour which can serve as an, albeit often unreliable, means of detection. (Refer to Table 5.12.)

An elementary introduction to chemistry is given in Chapter 3; this serves only to provide background and for more advanced consideration reference will be necessary to specific text books, e.g. as listed in the Bibliography. A brief discussion of the relevance of physicochemical principles to hazard identification is given in Chapter 4. Relevant toxic and flammable properties, and summaries of appropriate precautions to cater for them during handling, use and disposal, are provided in Chapters 5 and 6, respectively. Reactive hazards are discussed in Chapter 7. The special problems with cryogenic materials and chemicals under pressure, typified by compressed

**Table 1.3 Comprehensive information possibly required for a hazardous chemical**


---

Name of chemical; other names

Uses

General description of hazards

General description of precautions

Fire-fighting methods

Regulations

Sources of advice on precautions

**Characteristics: evaluate as appropriate under all process conditions**

Formula (chemical structure)

Purity (identity of any contaminants), physical state, appearance, other relevant information

Concentration, odour, detectable concentration, taste

*Physical characteristics*

Molecular weight

Vapour density

Specific gravity

Melting point

Boiling point

Solubility/miscibility with water

Viscosity

Particle size; size distribution

Foaming/emulsification characteristics

Critical temperature/pressure

Expansion coefficient

Surface tension

Joule–Thompson effect

Caking properties

Corrosivity

Contamination factors (incompatibility), oxidizing or reducing agent, dangerous reactions

*Flammability information*

Flash point

Fire point

Flammable limits (LEL, UEL)

Ignition temperature

Spontaneous heating

Toxic thermal degradation products

Vapour pressure

Dielectric constant

Electrical resistivity

Electrical group

Explosion properties of dust in a fire

*Reactivity (instability) information*

Acceleration rate calorimetry

Differential thermal analysis (DTA)

Impact test

Thermal stability

Lead block test

Explosion propagation with detonation

Drop weight test

Thermal decomposition test

Influence test

Self-acceleration temperature

Card gap test (under confinement)

JANAF

Critical diameter

Pyrophoricity

*Toxicity information*

Toxic hazard rating

Hygiene standard (e.g. OEL, TLV)

Maximum allowable concentration (MAC)

Lethal concentration (LC<sub>50</sub>)Lethal dose (LD<sub>50</sub>)*Biological properties**Exposure effects*

Inhalation (general)

Respiratory irritation

Ingestion

Skin/eye irritation

Skin and respiratory sensitization

Mutagenicity

Teratogenicity

Carcinogenicity

*Radiation information*

Radiation survey

Alpha/beta/gamma/neutron exposure and contamination

gases, are dealt with in Chapters 8 and 9. The unique problems associated with radioactive chemicals are described in Chapter 11.

The foregoing relates mainly to normal laboratory or commercial quantities of chemicals. Additional considerations arise with those quantities of flammable, explosive, reactive, bulk toxic, or hypertoxic chemicals which constitute *major hazards*, i.e. which may pose a hazard to neighbouring factories, residents, services etc. or a more substantial potential risk to the environment. Within the UK the Control of Major Accident Hazards Regulations 1999 requires that the operator of any establishment where a dangerous substance listed in column 1 of Parts 2 or 3 of Schedule 1 (reproduced here as Tables 1.5 and 1.6) is present in a quantity equal to or greater than that listed in column 2 of those Parts shall notify the competent authority. Detailed procedures and precautions are then applicable to such sites depending partly upon whether they are 'lower tier' or 'upper tier', i.e. sites at which the quantity present is equal to or exceeds that listed in column 3. The special considerations with such installations are detailed in specialist texts noted in the Bibliography. In the UK the Planning (Hazardous Substances) Regulations 1992 also require the holder to obtain a 'hazardous substances consent' for any site on which it is intended to hold a bulk quantity of any of 71 substances above a 'controlled quantity' (Table 1.7).

**Table 1.4 Typical data on hazards to the environment**

---

|                                                           |
|-----------------------------------------------------------|
| Aquatic toxicity (e.g. to fish, algae, daphnia)           |
| Terrestrial toxicity (to plants, earthworms, bees, birds) |
| Biotic degradation                                        |
| Abiotic degradation                                       |
| Photodegradation                                          |
| Biochemical oxygen demand                                 |
| Chemical oxygen demand                                    |
| Hydrolysis as a function of pH                            |
| Bioaccumulation                                           |
| Oil/water partition coefficient                           |

---

To proceed to assess, and recommend control strategies for, any operation involving a mixture of chemicals – e.g. a chemical process, welding fume, mixed effluents – can be a complex exercise. It can rarely be solved by rigidly following a checklist, although checklists, examples of which are given in the various chapters, can provide useful guidelines. And although associated hazards are not covered here, the control of chemical hazards in the workplace cannot be achieved in isolation from a consideration of electrical, mechanical, ergonomic, biological and non-ionizing radiation hazards. Hence these must be included in any hazard analysis and control system.

To ensure that an operation is under control may necessitate environmental monitoring; this is summarized in Chapter 10. Principles of safe design are given in Chapter 12. General safety considerations, administration and systems of work requirements, including elementary first aid, are summarized in Chapter 13. For example, the recommended strategy is to include provision for appropriate first aid procedures within the system of work before specific chemicals are brought into use; to so order work practices that the risk of exposure is minimized; and in the event of an accident involving any but the most trivial injuries – with no foreseeable likelihood of complications or deterioration – to seek immediate medical assistance.

Additional considerations, e.g. relating to labelling, information supply and emergency procedures, arise when marketing and transporting chemicals. While – as with Chapter 13 and with control measures generally – what is required will vary with specific legislation and basic requirements are summarized in Chapters 14 and 15.

**Table 1.5 Schedule 1 Part 2 of the COMAH Regulations Named Substances (Explanatory notes omitted)**

| <i>Column 1</i><br><i>Dangerous substances</i>                                                                                                                                                                                                                                             | <i>Column 2</i><br><i>Quantity in tonnes</i> | <i>Column 3</i><br><i>Quantity in tonnes</i> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------|
| Ammonium nitrate (as described in Note 1 of this Part)                                                                                                                                                                                                                                     | 350                                          | 2500                                         |
| Ammonium nitrate (as described in Note 2 of this Part)                                                                                                                                                                                                                                     | 1250                                         | 5000                                         |
| Arsenic pentoxide, arsenic (V) acid and/or salts                                                                                                                                                                                                                                           | 1                                            | 2                                            |
| Arsenic trioxide, arsenious (III) acid and/or salts                                                                                                                                                                                                                                        | 0.1                                          | 0.1                                          |
| Bromine                                                                                                                                                                                                                                                                                    | 20                                           | 100                                          |
| Chlorine                                                                                                                                                                                                                                                                                   | 10                                           | 25                                           |
| Nickel compounds in inhalable powder form (nickel monoxide, nickel dioxide, nickel sulphide, trinickel disulphide, dinickel trioxide)                                                                                                                                                      | 1                                            | 1                                            |
| Ethylenimine                                                                                                                                                                                                                                                                               | 10                                           | 20                                           |
| Fluorine                                                                                                                                                                                                                                                                                   | 10                                           | 20                                           |
| Formaldehyde (concentration $\geq 90\%$ )                                                                                                                                                                                                                                                  | 5                                            | 50                                           |
| Hydrogen                                                                                                                                                                                                                                                                                   | 5                                            | 50                                           |
| Hydrogen chloride (liquefied gas)                                                                                                                                                                                                                                                          | 25                                           | 250                                          |
| Lead alkyls                                                                                                                                                                                                                                                                                | 5                                            | 50                                           |
| Liquefied extremely flammable gases (including LPG) and natural gas (whether liquefied or not)                                                                                                                                                                                             | 50                                           | 200                                          |
| Acetylene                                                                                                                                                                                                                                                                                  | 5                                            | 50                                           |
| Ethylene oxide                                                                                                                                                                                                                                                                             | 5                                            | 50                                           |
| Propylene oxide                                                                                                                                                                                                                                                                            | 5                                            | 50                                           |
| Methanol                                                                                                                                                                                                                                                                                   | 500                                          | 5000                                         |
| 4,4-Methylenebis (2-chloroaniline) and/or salts, in powder form                                                                                                                                                                                                                            | 0.01                                         | 0.01                                         |
| Methylisocyanate                                                                                                                                                                                                                                                                           | 0.15                                         | 0.15                                         |
| Oxygen                                                                                                                                                                                                                                                                                     | 200                                          | 2000                                         |
| Toluene diisocyanate                                                                                                                                                                                                                                                                       | 10                                           | 100                                          |
| Carbonyl dichloride (phosgene)                                                                                                                                                                                                                                                             | 0.3                                          | 0.75                                         |
| Arsenic trihydride (arsine)                                                                                                                                                                                                                                                                | 0.2                                          | 1                                            |
| Phosphorus trihydride (phosphine)                                                                                                                                                                                                                                                          | 0.2                                          | 1                                            |
| Sulphur dichloride                                                                                                                                                                                                                                                                         | 1                                            | 1                                            |
| Sulphur dioxide                                                                                                                                                                                                                                                                            | 15                                           | 75                                           |
| Polychlorodibenzofurans and polychlorodibenzodioxins (including TCDD), calculated in TCDD equivalent                                                                                                                                                                                       | 0.001                                        | 0.001                                        |
| The following CARCINOGENS:                                                                                                                                                                                                                                                                 |                                              |                                              |
| 4-Aminobiphenyl and/or its salts,<br>Benzidene and/or its salts,<br>Bis(chloromethyl) ether,<br>Chloromethyl ether,<br>Dimethylcarbamoyl chloride,<br>Dimethylnitrosoamine,<br>Hexamethylphosphoric triamide,<br>2-Naphthylamine and/or its salts,<br>1,3-Propane sultone, 4-Nitrodiphenyl | 0.001                                        | 0.001                                        |
| Automotive petrol and other petroleum spirits                                                                                                                                                                                                                                              | 5000                                         | 50 000                                       |

**Table 1.6 Schedule 1 Part 3 of the COMAH Regulations. Categories of substances and preparations not specifically named in Part 2. (Explanatory notes omitted)**

| <i>Column 1</i><br><i>Categories of dangerous substances</i>                                                 | <i>Column 2</i><br><i>Quantity in tonnes</i> | <i>Column 3</i><br><i>Quantity in tonnes</i> |
|--------------------------------------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------|
| 1. VERY TOXIC                                                                                                | 5                                            | 20                                           |
| 2. TOXIC                                                                                                     | 50                                           | 200                                          |
| 3. OXIDIZING                                                                                                 | 50                                           | 200                                          |
| 4. EXPLOSIVE (Where the substance or preparation falls within the definition given in Notes 2a)              | 50                                           | 200                                          |
| 5. EXPLOSIVE (Where the substance or preparation falls within the definition given in Notes 2b)              | 10                                           | 50                                           |
| 6. FLAMMABLE (Where the substance or preparation falls within the definition given in Notes 3a)              | 5000                                         | 50 000                                       |
| 7a. HIGHLY FLAMMABLE (Where the substance or preparation falls within the definition given in Notes 3bi)     | 50                                           | 200                                          |
| 7b. HIGHLY FLAMMABLE (Where the substance or preparation falls within the definition given in Notes 3bii)    | 5000                                         | 50 000                                       |
| 8. EXTREMELY FLAMMABLE (Where the substance or preparation falls within the definition given in Notes 3c)    | 10                                           | 50                                           |
| 9. DANGEROUS FOR THE ENVIRONMENT in combination with risk phrases                                            |                                              |                                              |
| (i) R50: Very toxic to aquatic organisms                                                                     | 200                                          | 500                                          |
| (ii) R51: Toxic to aquatic organisms and R43: may cause long-term adverse effects in the aquatic environment | 500                                          | 2000                                         |
| 10. ANY CLASSIFICATION not covered by those given above in combination with risk phrases                     |                                              |                                              |
| (i) R14: Reacts violently with water (including R15)                                                         | 100                                          | 500                                          |
| (ii) R29: In contact with water, liberates toxic gas                                                         | 50                                           | 200                                          |

**Table 1.7 Planning (Hazardous Substances) Regulations 1992**  
**Hazardous substances and controlled quantities**

| <i>Hazardous substance</i>                                                                                                                                                                                                                                                                                                                                                                                                                                           | <i>Controlled quantity</i> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <b>Part A Toxic substances</b>                                                                                                                                                                                                                                                                                                                                                                                                                                       |                            |
| 1. Acetone cyanohydrin (2-cyanopropan-2-ol)                                                                                                                                                                                                                                                                                                                                                                                                                          | 200 t                      |
| 2. Acrolein (2-propenal)                                                                                                                                                                                                                                                                                                                                                                                                                                             | 200 t                      |
| 3. Acrylonitrile                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 20 t                       |
| 4. Allyl alcohol (2-propen-1-ol)                                                                                                                                                                                                                                                                                                                                                                                                                                     | 200 t                      |
| 5. Allylamine                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 200 t                      |
| 6. Ammonia (anhydrous or as solution containing more than 50% by weight of ammonia)                                                                                                                                                                                                                                                                                                                                                                                  | 100 t                      |
| 7. Arsenic trioxide, arsenious (III) acid and salts                                                                                                                                                                                                                                                                                                                                                                                                                  | 1 t                        |
| 8. Arsine (arsenic hydride)                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1 t                        |
| 9. Bromine                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 40 t                       |
| 10. Carbon disulphide                                                                                                                                                                                                                                                                                                                                                                                                                                                | 20 t                       |
| 11. Chlorine                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 10 t                       |
| 12. Ethylene dibromide (1,2-dibromoethane)                                                                                                                                                                                                                                                                                                                                                                                                                           | 50 t                       |
| 13. Ethyleneimine                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 50 t                       |
| 14. Formaldehyde (>90%)                                                                                                                                                                                                                                                                                                                                                                                                                                              | 50 t                       |
| 15. Hydrogen chloride (liquefied gas)                                                                                                                                                                                                                                                                                                                                                                                                                                | 250 t                      |
| 16. Hydrogen cyanide                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 20 t                       |
| 17. Hydrogen fluoride                                                                                                                                                                                                                                                                                                                                                                                                                                                | 10 t                       |
| 18. Hydrogen selenide                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1 t                        |
| 19. Hydrogen sulphide                                                                                                                                                                                                                                                                                                                                                                                                                                                | 50 t                       |
| 20. Methyl bromide (bromomethane)                                                                                                                                                                                                                                                                                                                                                                                                                                    | 200 t                      |
| 21. Methyl isocyanate                                                                                                                                                                                                                                                                                                                                                                                                                                                | 150 kg                     |
| 22. Nickel tetracarbonyl                                                                                                                                                                                                                                                                                                                                                                                                                                             | 1 t                        |
| 23. Nitrogen oxides                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 50 t                       |
| 24. Oxygen difluoride                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1 t                        |
| 25. Pentaborane                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 1 t                        |
| 26. Phosgene                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 750 kg                     |
| 27. Phosphine (hydrogen phosphide)                                                                                                                                                                                                                                                                                                                                                                                                                                   | 1 t                        |
| 28. Propyleneimine                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 50 t                       |
| 29. Selenium hexafluoride                                                                                                                                                                                                                                                                                                                                                                                                                                            | 1 t                        |
| 30. Stibine (antimony hydride)                                                                                                                                                                                                                                                                                                                                                                                                                                       | 1 t                        |
| 31. Sulphur dioxide                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 20 t                       |
| 32. Sulphur trioxide (including the sulphur trioxide content in oleum)                                                                                                                                                                                                                                                                                                                                                                                               | 15 t                       |
| 33. Tellurium hexafluoride                                                                                                                                                                                                                                                                                                                                                                                                                                           | 1 t                        |
| 34. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)                                                                                                                                                                                                                                                                                                                                                                                                                       | 1 kg                       |
| 35. Tetraethyl lead                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 50 t                       |
| 36. Tetramethyl lead                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 50 t                       |
| <b>Part B Highly reactive substances and explosive substances</b>                                                                                                                                                                                                                                                                                                                                                                                                    |                            |
| 37. Acetylene (ethyne) when a gas subject to a pressure $\leq 620$ millibars above that of the atmosphere, and not otherwise deemed to be an explosive by virtue of Order in Council No 30, <sup>(a)</sup> as amended by the Compressed Acetylene Order 1947, <sup>(b)</sup> or when contained in a homogeneous porous substance in cylinders in accordance with Order of Secretary of State No 9, <sup>(c)</sup> made under the Explosives Act 1875. <sup>(d)</sup> | 50 t                       |
| 38. Ammonium nitrate and mixtures containing ammonium nitrate where the nitrogen content derived from the ammonium nitrate >28% of the mixture by weight other than: (i) mixtures to which the Explosives Act 1875 applies; (ii) ammonium nitrate based products manufactured chemically for use as fertilizer which comply with Council Directive 80/876/EEC; <sup>(e)</sup> or (iii) compound fertilizers.                                                         | 500 t                      |
| 39. Aqueous solutions containing >90 parts by weight of ammonium nitrate per 100 parts by weight of solution.                                                                                                                                                                                                                                                                                                                                                        | 500 t                      |
| 40. Ammonium nitrate based products manufactured chemically for use as fertilizers which comply with Council Directive 80/876/EEC and compound fertilizers where the nitrogen content derived from the ammonium nitrate >28% of the mixture by weight.                                                                                                                                                                                                               | 1000 t                     |
| 41. 2,2-Bis(tert-butylperoxy)butane (>70%)                                                                                                                                                                                                                                                                                                                                                                                                                           | 5 t                        |
| 42. 1,1-Bis(tert-butylperoxy)cyclohexane (>80%)                                                                                                                                                                                                                                                                                                                                                                                                                      | 5 t                        |

Table 1.7 Cont'd

| <i>Hazardous substance</i>                                                                                                                                                                                                                                                                                                     | <i>Controlled quantity</i> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| 43. tert-Butyl peroxyacetate (>70%)                                                                                                                                                                                                                                                                                            | 5 t                        |
| 44. tert-Butyl peroxyisobutyrate (>80%)                                                                                                                                                                                                                                                                                        | 5 t                        |
| 45. tert-Butyl peroxyisopropylcarbonate (>80%)                                                                                                                                                                                                                                                                                 | 5 t                        |
| 46. tert-Butyl peroxy maleate (>80%)                                                                                                                                                                                                                                                                                           | 5 t                        |
| 47. tert-Butyl peroxy pivalate (>77%)                                                                                                                                                                                                                                                                                          | 5 t                        |
| 48. Cellulose nitrate other than:<br>(i) cellulose nitrate to which the Explosives Act 1875 applies; or<br>(ii) solutions of cellulose nitrate where the nitrogen content of the cellulose nitrate $\leq 12.3\%$ by weight and the solution contains $\leq 55$ parts of cellulose nitrate per 100 parts by weight of solution. | 50 t                       |
| 49. Dibenzyl peroxydicarbonate (>90%)                                                                                                                                                                                                                                                                                          | 5 t                        |
| 50. Diethyl peroxydicarbonate (>30%)                                                                                                                                                                                                                                                                                           | 5 t                        |
| 51. 2,2-Dihydroperoxypropane (>30%)                                                                                                                                                                                                                                                                                            | 5 t                        |
| 52. Di-isobutyl peroxide (>50%)                                                                                                                                                                                                                                                                                                | 5 t                        |
| 53. Di-n-propyl peroxydicarbonate (>80%)                                                                                                                                                                                                                                                                                       | 5 t                        |
| 54. Di-sec-butyl peroxydicarbonate (>80%)                                                                                                                                                                                                                                                                                      | 5 t                        |
| 55. Ethylene oxide                                                                                                                                                                                                                                                                                                             | 5 t                        |
| 56. Ethyl nitrate                                                                                                                                                                                                                                                                                                              | 50 t                       |
| 57. 3,3,6,6,9,9-Hexamethyl-1,2,4,5-tetroxacyclononane (>75%)                                                                                                                                                                                                                                                                   | 5 t                        |
| 58. Hydrogen                                                                                                                                                                                                                                                                                                                   | 2 t                        |
| 59. Liquid oxygen                                                                                                                                                                                                                                                                                                              | 500 t                      |
| 60. Methyl ethyl ketone peroxide (>60%)                                                                                                                                                                                                                                                                                        | 5 t                        |
| 61. Methyl isobutyl ketone peroxide (>60%)                                                                                                                                                                                                                                                                                     | 5 t                        |
| 62. Peracetic acid (>60%)                                                                                                                                                                                                                                                                                                      | 5 t                        |
| 63. Propylene oxide                                                                                                                                                                                                                                                                                                            | 5 t                        |
| 64. Sodium chlorate                                                                                                                                                                                                                                                                                                            | 25 t                       |
| 65. Sulphur dichloride                                                                                                                                                                                                                                                                                                         | 1 t                        |
| <b>Part C Flammable substances (unless specifically named in Parts A and B)</b>                                                                                                                                                                                                                                                |                            |
| 66. Liquefied petroleum gas, such as commercial propane and commercial butane, and any mixtures thereof, when held at a pressure $>1.4$ bar absolute.                                                                                                                                                                          | 25 t                       |
| 67. Liquefied petroleum gas, such as commercial propane and commercial butane, and any mixture thereof, when held under refrigeration at a pressure $\leq 1.4$ bar absolute.                                                                                                                                                   | 50 t                       |
| 68. Gas or any mixture of gases which is flammable in air, when held as a gas.                                                                                                                                                                                                                                                 | 15 t                       |
| 69. A substance or any mixture of substances, which is flammable in air, when held above its boiling point (measured at 1 bar absolute) as a liquid or as a mixture of liquid and gas at a pressure $>1.4$ bar absolute.                                                                                                       | 25 t                       |
| 70. A liquefied gas or any mixture of liquefied gases, which is flammable in air and has a boiling point $<0$ C (measured at 1 bar absolute), when held under refrigeration or cooling at a pressure $\leq 1.4$ bar absolute.                                                                                                  | 50 t                       |
| 71. A liquid or any mixture of liquids not included in entries 68 to 70 above, which has a flash point $<21$ C.                                                                                                                                                                                                                | 10 000 t                   |

(a) S.R. &amp; O. 1937/54.

(b) S.R. &amp; O. 1947/805.

(c) S.R. &amp; O. 1919/869.

(d) 1875 c.17.

(e) OJ No L250, 23.9.80, p. 7.

All chemical operations produce waste either as solid wastes (including pastes, sludge and drummed liquids), liquid effluents, or gaseous emissions (including gases, particulate solids, mists and fogs). Relevant data are summarized in Chapters 16 and 17.

Since data have been collated from a variety of sources, and tend to be presented in mixed units, and because rapid conversion of units is an advantage in many on-site situations, conversion tables are included in Chapter 18. Finally, since safety with chemicals cannot be addressed exhaustively in a handbook, selected sources of reliable current information on chemical hazards and their control are listed in Chapter 19.



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# Terminology

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**ACID** A chemical compound whose aqueous solution turns blue litmus paper red, reacts with and dissolves certain metals to form salts, and reacts with bases to produce salts and water. They are capable of transferring a hydrogen ion (proton) in solution.

**ACUTE** Describes a severe and often dangerous condition in which relatively rapid changes occur.

**ACUTE TOXICITY** Adverse health effects occurring within a short time period of exposure to a single dose of a chemical or as a result of multiple exposures over a short time period, e.g. 24 hours.

**AEROSOL** A colloidal suspension of liquid or solid particles dispersed in gas.

**AFFF, AQUEOUS FILM-FORMING FOAM** Fire-fighting foam which flows on burning liquid as a film, providing rapid knock-down.

**ALCOHOL-RESISTANT FOAM** Foam for use against fires involving liquids miscible with water, e.g. alcohol, acetone.

**ANION** A negatively charged atom or group of atoms, or a radical which moves to the positive pole (anode) during electrolysis.

**ANOXIA** Deficient supply of oxygen to tissues.

**ANTIBODY** A modified protein circulating in the serum of an animal, synthesized in response to a foreign molecule (antigen) that has entered the body.

**ANTIGEN** A foreign substance (usually a protein) that stimulates formation of antibody.

**ASPHYXIA** The result of a diminished supply of oxygen to the blood and tissues and interference with the respiratory function. Simple anoxia may be caused by 'inert gases', e.g. nitrogen, and some flammable gases, e.g. methane. Toxic anoxia may be caused by certain substances, e.g. carbon monoxide and hydrogen cyanide, which interfere with the body's ability to transfer or utilize oxygen in the tissues. Rapid unconsciousness and death can occur in either case.

**ASTHMA** Periodic attacks of wheezing, chest tightness and breathlessness resulting from constriction of the airways.

**ATOM** The smallest unit of an element incapable of further subdivision in the course of a chemical reaction.

**ATOMIC NUMBER** The number of protons in an atomic nucleus.

**ATOPY** Hypersensitivity where tendency to allergy is inherited.

**AUTO-IGNITION TEMPERATURE** The minimum temperature required to initiate or cause self-sustained combustion of material in the absence of any external source of energy. (Values may change significantly with geometry, gas/vapour concentration, and presence of catalyst.) Any ignition source must be at a temperature of, or greater than, the ignition temperature of the specific substance.

**BASE** A chemical compound whose aqueous solution turns red litmus paper blue and is capable of accepting or receiving a proton from another substance. They react with acids to form salts and water.

**BATNEEC** Term used in the Environmental Protection Act and other legislation. Certain polluting processes are required to use the Best Available Techniques Not Entailing Excessive Cost (BATNEEC) to reduce the environmental impact of a prescribed process as far as possible. Environment Agency inspectors determine what constitutes BATNEEC for each application and are to change the definition as improved technologies or techniques become available.

**BIOCHEMICAL OXYGEN DEMAND (BOD)** Official term given to measure how polluting organic industrial effluent is when it is discharged into water. This effluent is feed for bacteria which consume oxygen, making it more difficult for plant and fish life to survive. The lower the BOD level, the less polluting the effluent.

**BLACK LIST** The Black List was introduced by the EC in Directive 76/464/EEC on dangerous substances released into water as list I. It contains substances selected mainly on the basis of their toxicity, persistence and accumulation in living organisms and in sediment.

**BEST PRACTICABLE ENVIRONMENTAL OPTION (BPEO)** Organizations may be encouraged to undertake systematic decision processes with a view to seeking the BPEO that provides the most benefit (or least damage) to the environment, at an acceptable cost.

**BLEVE, BOILING LIQUID EXPANDING VAPOUR EXPLOSION** Instantaneous release and ignition of flammable vapour upon rupture of a vessel containing flammable liquid above its atmospheric boiling point.

**BLOWING AGENT** Chemical liable to decomposition at low temperature to produce a large volume of gas.

**CARCINOGEN** An agent (whether chemical, physical or biological) capable of increasing the incidence of malignant neoplasms. Defined in Regulation 2 of the Control of Substances Hazardous to Health Regulations 1999 as:

- (a) any substance or preparation which if classified in accordance with the classification provided for by Regulation 5 of the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 would be in the category of danger, carcinogenic (category 1) or carcinogenic (category 2) whether or not the substance or preparation would be required to be classified under those Regulations; or
- (b) any substance or preparation:
  - (i) listed in Schedule 1, or
  - (ii) arising from a process specified in Schedule 1 which is a substance hazardous to health.

**CATION** A positively charged atom or group of atoms, or a radical which moves to the negative pole (cathode) during electrolysis.

**CHEMICAL BOND** Strong forces of attraction holding atoms together in molecules or crystalline salts.

**CHLOROFLUOROCARBONS (CFCS)** Organic substances containing chlorine and fluorine which were

initially thought to be harmless and found extensive use, e.g., as propellants because they are largely non-flammable. Some CFCs have since been found to be one of the main sources of atmospheric ozone depletion and a greenhouse gas. Until recently they were used extensively as aerosol propellants, solvents, refrigerants and in foam making. Many countries have now agreed to eliminate CFCs as soon as possible.

**CHLORINATED HYDROCARBONS** Hydrocarbons containing chlorine atoms, e.g. trichloroethylene. Some of these chemicals accumulate in the food chain and do not readily degrade. Some plastics which contain certain chlorinated hydrocarbons release dioxins into the air, when burnt at low temperatures.

**CHRONIC** Occurring for a prolonged period.

**CHRONIC TOXICITY** Adverse health effects resulting from repeated daily exposures to a chemical for a significant period.

**CLASS A FIRE** A fire involving solids, normally organic, in which combustion generally occurs with the formation of glowing embers.

**CLASS A POISON (USA)** A toxic gas/liquid of such a nature that a very small amount of the gas, or vapour of the liquid, in air is dangerous to life.

**CLASS B FIRE** A fire involving liquids or liquefiable solids.

**CLASS B POISON (USA)** Any substance known to be so toxic that it poses a severe health hazard during transportation.

**CLASS C FIRE** A fire involving gases or liquefied gases in the form of a liquid spillage, or a liquid or gas leak.

**CLASS D FIRE** A fire involving metals.

**CNS DEPRESSANT** Substances, e.g. anaesthetics and narcotics, which depress the activity of the central nervous system. Symptoms following exposure include headache, dizziness, loss of consciousness, respiratory or cardiac depression, death.

**CONFINED SPACE** A space which is substantially, although not always entirely, enclosed and where there is a reasonably foreseeable risk of serious injury from hazardous substances or conditions within the space or nearby. The risks may include flammable substances; oxygen deficiency or enrichment; toxic gases, fume or vapour; ingress or presence of liquids; free-flowing solids; presence of excessive heat. For the purpose of the Confined Spaces Regulations 1997 a 'confined space' means any place, including any chamber, tank, vat, silo, pit, trench, pipe, sewer, flue, well or other similar space in which, by virtue of its enclosed nature, there arises a reasonably foreseeable specified risk.

**CONTACT DERMATITIS** Inflammation of the skin due to exposure to a substance that attacks its surface.

**CONTROLLED WASTE** All household, industrial or commercial waste of any quantity or description.

**CORROSIVE** A substance that chemically attacks a material with which it has contact (body cells, materials of construction).

**COSHH (CONTROL OF SUBSTANCES HAZARDOUS TO HEALTH)** The Control of Substances Hazardous to Health Regulations 1999 establish the responsibilities of employers with regard to all substances which pose a health hazard in the workplace.

**CRYOGEN** A substance used to obtain temperatures far below freezing point of water, e.g.  $< -78^{\circ}\text{C}$ .

**CVCE (CONFINED VAPOUR CLOUD EXPLOSION)** Explosion of a gas or vapour which is initially 'confined' within a vessel, building, piping, etc.

**DANGEROUS SUBSTANCES (UK)** Defined substances which may be hazardous to the fire services in an emergency. (Dangerous Substances (Notification and Marking of Sites) Regulations 1990.)

Defined substances over which control is exercised for conveyance in all road tankers or in tank containers >3 m<sup>3</sup> capacity. (The Carriage of Dangerous Goods by Road Regulations 1996.)

Defined substances covered by a comprehensive system to inform consumers of potential dangers and to reduce the hazard when carried by road. The Chemical (Hazard Information and Packaging for Supply Regulations 1994).

Defined substances, including all toxic gases, all flammable gases, asbestos and most hazardous wastes, for which carriage in packages or in bulk is controlled. (The Carriage of Dangerous Goods by Road Regulations 1996).

**DETONATION** Explosion in which the flamefront advances at more than supersonic velocity.

**DISCHARGE CONSENTS** Permission to discharge trade effluent directly into controlled waters is given by the National Rivers Authority in the form of a discharge consent which will specify amounts and conditions. Discharges to public sewers are controlled by discharge consents by one of the ten Water Service Companies.

**DUST** Solid particles generated by mechanical action, present as airborne contaminant (e.g. <75 µm in size).

**DUTY OF CARE** The concept of the duty of care for waste is set out in Section 34 of the Environmental Protection Act (1990) which states that it is the duty of any person who imports, produces, carries, keeps, treats or disposes of controlled waste to keep that waste properly under control.

**ECOTOXICOLOGY** The study of toxic effects of chemical and physical agents on living organisms as well as human beings, especially on populations and communities within defined ecosystems.

**ENDOTHERMIC REACTION** A chemical reaction resulting in absorption of heat.

**ENVIRONMENT AGENCY** The Environment Agency provides a comprehensive approach to the protection and management of the environment by combining the regulation of land, air and water. Its creation is a major and positive step, merging the expertise of the National Rivers Authority, Her Majesty's Inspectorate of Pollution, the Waste Regulation Authorities and several smaller units from the Department of the Environment.

**EPIDEMIOLOGY** The study in populations of health factors affecting the occurrence and resolution of disease and other health-related conditions.

**ERYTHEMA** Reddening of skin, inflammation.

**EXOTHERMIC REACTION** A chemical reaction in which heat is released and, unless temperature is controlled, may lead to runaway conditions.

**FIBROSIS** Scarring, usually of lung tissue.

**FIRE POINT** The minimum temperature at which a mixture of gas/vapour and air continues to burn in an open container when ignited. The value is generally above the flash point.

**FLAMMABLE RANGE** The concentrations of flammable gas or vapour between the LEL and UEL at a given temperature.

**FLASH POINT** The lowest temperature required to raise the vapour pressure of a liquid such that

**vapour concentration in air near the surface of the liquid is within the flammable range, and as such the air/vapour mixture will ignite in the presence of a suitable ignition source, usually a flame. (Open cup values are approximately 5.5 to 8.3 C higher than the closed cup values.)**

**FOG (MISTS)** Liquid aerosols formed either by condensation of a liquid on particulate nodes in air or by uptake of liquid by hygroscopic particles.

**FUME** Airborne solid particles (usually  $<0.1\text{ }\mu\text{m}$ ) that have condensed from the vapour state.

**HAZARD** The inherent property of a substance capable of causing harm (e.g. toxicity, radioactivity, flammability, explosivity, reactivity, instability). In a broader context anything that can cause harm, e.g. electricity, oxygen-deficiency, machinery, extreme temperature.

**HAZARDOUS WASTE** An unofficial class of industrial wastes which have to be disposed of with particular care. In the UK the closest definition is for 'special wastes'. Certain toxic organic wastes, such as PCBs, have to be burned in high-temperature incinerators.

**HEAVY METALS** A group of metals which are sometimes toxic and can be dangerous in high concentrations. The main heavy metals covered by legislation are cadmium, lead, and mercury. Industrial activities such as smelting, rubbish burning, waste disposal and adding lead to petrol increase the amount of toxic heavy metals in the environment.

**HUMIDIFIER FEVER** A flu-like illness caused by inhalation of fine droplets of water from humidifiers that have become contaminated.

**HYDROCARBONS** Organic compounds that contain only hydrogen and carbon. The major sources of hydrocarbons in the atmosphere are vehicle emissions (unburned fuel) and gas leaks. Contributes to acid rain.

**HYGIENE STANDARD** See OES, MEL, TLV.

**INERTING** Depression of the flammable limits of a flammable gas/vapour-air mixture by the addition of an inert gas, e.g. nitrogen, carbon dioxide, or similar mixtures, to render it non-flammable.

**ION** An isolated electron or positron, or an atom or molecule, which by loss or gain of one or more electrons has acquired a net electric charge.

**IONIZING RADIATION** The transfer of energy in the form of particles or electromagnetic waves of a wavelength of 100 nanometers or less or a frequency of  $3 \times 10^{15}$  hertz or more capable of producing ions directly or indirectly.

**ISOTOPE** One of two or more atoms having the same atomic number but different mass number.

**IPC (INTEGRATED POLLUTION CONTROL)** Under this new integrated approach to pollution control land, water and air are to be treated collectively rather than as separate environmental media. Industries are given consents to pollute with the effect on all three media being taken into consideration. IPC was introduced by the Environmental Protection Act (1990) and an EC system of Integrated Pollution, Prevention and Control is being introduced.

**JET FIRE** Fuel burning as a flame when flammable gas or vapour issues from a pipe, or other orifice, and burns on the orifice.

**KINETICS** The branch of physical chemistry concerned with measuring and studying the rates and mechanisms of chemical reactions.

**LANDFILL** Disposal of waste in the ground. This method is commonly used for both domestic waste and more hazardous chemical waste. Landfill sites used for difficult and potentially-dangerous wastes are now engineered, managed and monitored to prevent poisons leaking out.

**LC<sub>50</sub>** The calculated concentration of a substance that causes death in 50% of a test population under prescribed conditions in a prescribed period of time (normally expressed as ppm or mg/m<sup>3</sup> for gases, mg/l for liquids).

**LD<sub>50</sub>** The calculated dose of chemical (mg per kg body weight) causing death in 50% of test population. (The species of animal, route of administration, any vehicle used to dissolve or suspend the material, and the time period of exposure should be reported.)

**LEACHATE** Liquid that leaks from waste disposal sites. (In a broader sense liquid, e.g. solution, removed from a solid by a solvent, such as water.)

**LEGIONNAIRES' DISEASE** Infection caused by inhaling a fine spray of airborne water carrying *Legionella pneumophila* bacteria.

**LEL (LOWER EXPLOSIVE, OR FLAMMABLE, LIMIT)** The minimum concentration of a gas, vapour, mist or dust in air at a given pressure and temperature that will propagate a flame when exposed to an efficient ignition source. Generally expressed as % by volume for gases and vapours, and as mg/m<sup>3</sup> for mists or dusts.

**LPG (LIQUEFIED PETROLEUM GAS)** Petroleum gas stored or processed as a liquid in equilibrium with vapour by refrigeration or pressurization. The two LPGs in general use are commercial propane and commercial butane supplied to product specifications, e.g. BS 4250. (These, or mixtures thereof, comprise LPG for the purpose of the Highly Flammable Liquids and Liquefied Petroleum Gas Regulations 1972.)

**MAJOR ACCIDENT** An occurrence (including in particular, a major emission, fire or explosion) resulting from uncontrolled developments in the course of operation of any establishment and leading to serious danger to human health or the environment, and involving one or more dangerous substances. Requirements with respect to the control of major accident hazards involving dangerous substances apply to defined establishments under the Control of Major Accident Hazards Regulations 1999.

**MASS NUMBER** The sum of the number of protons and neutrons in the nucleus of an atom.

**MEL, MAXIMUM EXPOSURE LIMIT (UK)** The maximum concentration of an airborne substance (averaged over a reference period) to which employees may be exposed by inhalation under any circumstances. (Listed in 'Occupational exposure limits', EH40/HSE.)

**METAL FUME FEVER** Non-specific, self-limiting illness resembling an attack of influenza caused mainly by exposure to fumes of zinc, copper, or magnesium and less frequently due to exposure to other metal fumes. Exposures occur from molten metals, e.g. in smelting, galvanizing, welding.

**METALWORKING FLUID** Fluid applied to a tool and workpiece to cool, lubricate, carry away particles of waste and provide corrosion protection. Generally comprising neat mineral oils, or water-based materials, or a mixture of the two. Fluids may also contain emulsifiers, stabilizers, biocides, corrosion inhibitors, fragrances and extreme pressure additives.

**MINERAL OIL** Oil derived from petroleum. Includes a wide range of hydrocarbons from light oils, kerosene and gas oils, to the heavier fuel and lubricating oils.

**MOLECULES** Groups of atoms held together by strong chemical forces and forming the smallest unit of a compound. The atoms may be identical, e.g. H<sub>2</sub> or different, e.g. H<sub>2</sub>O.



**MULTIPLE CHEMICAL SENSITIVITY** An acquired disorder characterized by recurrent symptoms, referable to multiple organ systems, occurring in response to many chemically-unrelated compounds at doses far below those established in the general population to cause harmful effects. No single widely accepted test of physiologic function can be shown to correlate with symptoms.

**MUTAGEN** A chemical or physical agent that can cause a change (mutation) in the genetic material of a living cell.

**NARCOSIS** Drowsiness or sleepiness.

**NATURAL GAS** Flammable gas consisting essentially of methane with very minor proportions of other gases. Flammable limits approximately 5–15%. Odourized for commercial distribution within the UK.

**NRA (NATIONAL RIVERS AUTHORITY)** The National Rivers Authority were the body responsible for the management of water resources and the control of water pollution in England and Wales. They are now part of the Environment Agency.

**ODOUR THRESHOLD** The minimum concentration of a substance at which the majority of test subjects can detect and identify the substance's characteristic odour.

**OES, OCCUPATIONAL EXPOSURE STANDARD (UK)** The concentration of an airborne substance (averaged over a reference period) at which, according to current knowledge, there is no evidence that it is likely to be injurious to employees if they are exposed by inhalation, day after day. (Specified by HSC in Guidance Note EH40.)

**OXIDIZING AGENT** Compound that gives up oxygen easily or removes hydrogen from another compound. It may comprise a gas, e.g. oxygen, chlorine, fluorine, or a chemical which releases oxygen, e.g. a nitrate or perchlorate. A compound that attracts electrons.

**OXYGEN DEFICIENCY** Depletion of oxygen content in an atmosphere to below the normal 21%. Exposure to <18% must not be permitted. Concentrations 6% to 10% oxygen can lead to loss of consciousness.

**OXYGEN ENRICHMENT** Increase in oxygen content of air to above the normal 21%. Enrichment within a room to >25% can promote or accelerate combustion.

**OZONE** A reactive form of oxygen the molecule of which contains 3 atoms of oxygen. In the ozone layer it protects the earth by filtering out ultra-violet rays. At ground level, as a constituent of photochemical smog, it is an irritant and can cause breathing difficulties.

**OZONE LAYER** A thin layer of ozone that lies about 25 kilometres above the earth in the stratosphere. Forms a protective screen against harmful radiation by filtering out ultra-violet rays from the sun.

**PARAOCUPATIONAL EXPOSURE** Exposure of workers to an airborne contaminant from a nearby process or operation not forming part of their jobs. Also termed 'neighbourhood exposure'.

**PCBS (POLYCHLORINATED BIPHENYLS)** Toxic synthetic chemicals with excellent heat resistance and low electrical conductivity properties. Now little used but considerable quantities remain in old electrical equipment. Produces dioxins and polychlorinated dibenzo-furans when burned below 1200 C. PCBs are toxic and bio-accumulative.

**PERCUTANEOUS ABSORPTION** Absorption via the skin, e.g. due to local contamination or a splash of chemical.

**PERMIT-TO-WORK** A document needed when the safeguards provided in normal production are

unavailable and the manner in which a job is done is critical to safety. Identifies conditions required for safe operation.

**PNEUMOCONIOSIS** A group of lung diseases of a chronic fibrotic character due to the inhalation and retention in the lungs of a variety of industrial dusts. The main diseases are asbestosis, silicosis, coalworkers' pneumoconiosis and mixed-dust pneumoconiosis; less common pneumoconioses are associated with talc, clay or aluminium.

**POOL FIRE** A fire involving a flammable liquid spillage onto ground or onto water, or within a storage tank or trench. The pool size depends upon the scale and local topography. Fire engulfment and radiant heat pose the main risks.

**PRACTICABLE** Capable of being done in the light of current knowledge and invention.

**PRESCRIBED DISEASE** A disease prescribed for the purpose of payment of disablement benefit under the Social Security Act 1975 and the Social Security (Industrial Injuries) (Prescribed Diseases) Regulations 1985 and subsequent amendments. (Conditions due to physical agents, biological agents and miscellaneous conditions are classified in addition to conditions due to chemical agents.)

**PRESCRIBED PROCESS** Industrial process which requires an official authorization because of the likelihood of causing pollution under the provisions of the Environmental Protection Act (1990).

**PRESCRIBED SUBSTANCE** A substance controlled by Section I of the Environmental Protection Act (1990) because of its potential to pollute. Different substances are prescribed for release to different environmental media.

**PRESSURE SYSTEM** Defined in the Pressure System Safety Regulations 2000 as a system containing one or more pressure vessels of rigid construction, any associated pipework and protective devices; the pipework with its protective devices to which a transportable gas container is, or is intended to be, connected; or a pipeline and its protective devices which contains or is liable to contain a relevant fluid, but does not include a transportable gas container. Here 'relevant fluid' is steam; any fluid or mixture of fluids which is at a pressure of >0.5 bar above atmospheric pressure, and which fluid or a mixture of fluids is a gas, or a liquid which would have a vapour pressure of >0.5 bar above atmospheric pressure when in equilibrium with its vapour at either the actual temperature of the liquid or 17.5°C; or a gas dissolved under pressure in a solvent contained in a porous substance at ambient temperature and which could be released from the solvent with the application of heat.

**PULMONARY OEDEMA** Production of watery fluid in the lungs.

**PYROPHORIC SUBSTANCE** A material that undergoes such vigorous oxidation or hydrolysis (often with evolution of highly-flammable gases) when exposed to atmospheric oxygen or to water, that it rapidly ignites without an external source of ignition. This is a special case of spontaneous combustion.

**REASONABLY PRACTICABLE** The implication that the quantum of risk is balanced against the sacrifice or cost in terms of money, time and trouble necessary to avert that risk. If the risk outweighs the sacrifice or cost, additional precautions are necessary.

**RECYCLING** The use of materials, usually after further processing, which otherwise would be thrown away. Becoming common practice in industry, especially with expensive commodities such as chemical solvents although many products require a commercial subsidy in order to make recycling viable.

**RED LIST** The Red List was drawn up by the UK Government in 1989 in response to international



conferences of the states bordering the North Sea. The aim was to reduce inputs of Red List substances by 50% by 1995, from 1985 levels. All those substances listed on the Red List are included on the EC Black List.

Authorizations to discharge Red List substances are dealt with by the Environment Agency under Integrated Pollution Control (IPC).

**REDUCING AGENT** A material that adds hydrogen to an element or compound; a material that adds an electron to an element or compound.

**REPORTABLE DISEASE (UK)** A disease which must be reported to the authorities when linked to specified types of work. (The Reporting of Injuries Diseases and Dangerous Occurrences Regulations 1995.)

**RESPIRABLE DUST** That fraction of total inhalable dust which penetrates to the gas exchange region of the lung (usually considered to be in the range  $0.5\text{ }\mu\text{m}$ – $7\text{ }\mu\text{m}$ ).

**RESPIRATORY SENSITIZER (ASTHMAGEN)** A substance which can cause an individual's respiratory system to develop a condition which makes it 'over-react' if the substance is inhaled again. Such an individual is 'sensitized'; over-reaction is then likely to occur at concentrations of the substance which have no effect on unsensitized persons and lead to characteristic symptoms, e.g. rhinitis (a runny nose), conjunctivitis or in severe cases asthma or alveolitis.

**RISK** The likelihood that a substance will cause harm in given circumstances.

**SAFE SYSTEM OF WORK** A formal procedure resulting from systematic examination of a task to identify all the hazards. Defines safe methods to ensure that hazards are eliminated or risks controlled.

**SEALED SOURCE** A source containing any radioactive substance whose structure is such as to prevent, under normal conditions of use, any dispersion of radioactive substances into the environment, but it does not include any radioactive substance inside a nuclear reactor or any nuclear fuel element.

**SENSITIZATION DERMATITIS** Inflammation of the skin due to an allergic reaction to a sensitizer.

**SENSITIZER** A substance that causes little or no reaction in a person upon initial exposure but which will provoke an allergic response on subsequent exposures.

**SICK BUILDING SYNDROME** A group of symptoms more common in workers in certain buildings and which are temporarily related to working in them. Symptoms include lethargy, tiredness, headache; also sore/dry eyes, dry throat, dry skin, symptoms suggestive of asthma, blocked or runny nose. Cause is multifunctional but does include agents encountered in the workplace.

**SMOKE** Particulate matter (usually  $<0.5\text{ }\mu\text{m}$  in diameter) in air resulting usually from combustion, including liquids, gases, vapours and solids.

**SOLVENTS** Liquids that dissolve other substances. Chemical solvents are used widely in industry: e.g. by pharmaceutical makers to extract active substances; by electronics manufacturers to wash circuit boards; by paint makers to aid drying. Solvents can cause air and water pollution and some can be responsible for ozone depletion.

**SPECIAL WASTE** Controlled waste which is subject to special regulations regarding its control and disposal because of its difficult or dangerous characteristics. The UK definition of special waste is similar, but not identical, to the EC's hazardous waste.

**SPONTANEOUS COMBUSTION** Combustion that results when materials undergo atmospheric oxidation

at such a rate that the heat generation exceeds heat dissipation and the heat gradually builds up to a sufficient degree to cause the mass of material to inflame.

**STEAM EXPLOSION** Overpressure associated with the rapid expansion in volume on instantaneous conversion of water to steam.

**SUBSTANCE HAZARDOUS TO HEALTH** As defined in Regulation 2 of the Control of Substances Hazardous to Health Regulations 1999,

- (a) a substance which is listed in Part 1 of the approved supply list as dangerous for supply within the meaning of the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 and for which an indication of danger specified for the substance in Part V of that list is very toxic, toxic, harmful, corrosive or irritant;
- (b) a substance for which the Health and Safety Commission has approved a maximum exposure limit or an occupational exposure standard;
- (c) a biological agent;
- (d) dust of any kind except of a substance within para. (a) or (b) above, when present at a concentration in air equal to or greater than:
  - (i) 10 mg/m<sup>3</sup>, as a time-weighted average over an 8-hr period, of total inhalable dust, or
  - (ii) 4 mg/m<sup>3</sup>, as a time-weighted average over an 8-hr period of respirable dust;
- (e) a substance, not covered by (a) or (b) above, which creates a hazard to the health of any person which is comparable with the hazards created by substances mentioned in those subparagraphs.

**SYNERGISTIC** When the combined effect, e.g. of exposure to a mixture of toxic chemicals, is greater than the sum of the individual effects.

**SYSTEMIC POISONS** Substances which cause injury at sites other than, or as well as, at the site of contact.

**TERATOGEN** A chemical or physical agent that can cause defects in a developing embryo or foetus when the pregnant female is exposed to the harmful agent.

**THERMODYNAMICS** The study of laws that govern the conversion of one form of energy to another.

**TLV-C, THRESHOLD LIMIT VALUE – CEILING (USA)** A limit for the atmospheric concentration of a chemical which may not be exceeded at any time, even instantaneously in workroom air.

**TLV-STEL, THRESHOLD LIMIT VALUE – SHORT TERM EXPOSURE LIMIT (USA)** A maximum limit on the concentration of a chemical in workroom air which may be reached, but not exceeded, on up to four occasions during a day for a maximum of 15 minutes each time with each maximum exposure separated by at least one hour.

**TLV-TWA, THRESHOLD LIMIT VALUE – TIME WEIGHTED AVERAGE (USA)** A limit for the atmospheric concentration of a chemical, averaged over an 8-hr day, to which it is believed that most people can be exposed without harm.

**TOTAL INHALABLE DUST** Airborne material capable of entering the nose and mouth during breathing and hence available for deposition in the respiratory tract.

**TOXIC WASTE** Poisonous waste, usually certain organic chemicals such as chlorinated solvents.

**TRADE EFFLUENT** Any waste water released from an industrial process or trade premises with the exception of domestic sewage.

UEL, UPPER EXPLOSIVE (OR FLAMMABLE) LIMIT The maximum concentration of gas, vapour, mist or dust in air at a given pressure and temperature in which a flame can be propagated.

UVCE (UNCONFINED VAPOUR CLOUD EXPLOSION) Explosion which may occur when a large mass of flammable vapour, normally >5 tonnes, after dispersion in air to produce a mixture within the flammable range is ignited in the open. Intense blast damage results, often causing 'domino effects', e.g. secondary fires.

VALENCY The number of potential chemical bonds that an element may form with other elements.

VOCS (VOLATILE ORGANIC COMPOUNDS) Gaseous pollutants whose sources include vehicle emissions and solvents.

WDAS (WASTE DISPOSAL AUTHORITIES) Body responsible for planning and making arrangements for waste disposal in their area with the waste disposal companies and for providing household waste dumps under the Environmental Protection Act 1990.

# General principles of chemistry

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## Introduction

This chapter provides a brief insight into selected fundamental principles of matter as a background to the appreciation of the hazards of chemicals.

Chemistry is the science of chemicals which studies the laws governing their formation, combination and behaviour under various conditions. Some of the key physical laws as they influence chemical safety are discussed in Chapter 4.

## Atoms and molecules

Chemicals are composed of atoms, discrete particles of matter incapable of further subdivision in the course of a chemical reaction. They are the smallest units of an element. Atoms of the same element are identical and equal in weight. All specimens of gold have the same melting point, the same density, and the same resistance to attack by mineral acids. Similarly, all samples of iron of the same history will have the same magnetism. Atoms of different elements have different properties and differ in weight.

Atoms are comprised of negatively charged electrons orbiting a nucleus containing positively-charged protons and electrically-neutral neutrons as described in Chapter 11. The orbits of electrons are arranged in energy shells. The first shell nearest to the nucleus can accommodate two electrons, the second shell up to eight electrons, the third 18 electrons, and the fourth 32 electrons. This scheme is the 'electronic configuration' and largely dictates the properties of chemicals. Examples are given in Table 3.1.

Chemicals are classed as either elements or compounds. The former are substances which cannot be split into simpler chemicals, e.g. copper. There are 90 naturally-occurring elements and 17 artificially produced. In nature the atoms of some elements can exist on their own, e.g. gold, whilst in others they link with other atoms of the same element to form molecules, e.g. two hydrogen atoms combine to form a molecule of hydrogen. Atoms of different elements can combine in simple numerical proportions 1:1, 1:2, 1:3, etc. to produce compounds, e.g. copper and oxygen combine to produce copper oxide; hydrogen and oxygen combine to produce water. Compounds are therefore chemical substances which may be broken down to produce more than one element. Molecules are the smallest unit of a compound.

Substances such as brass, wood, sea water, and detergent formulations are *mixtures* of chemicals. Two samples of brass may differ in composition, colour and density. Different pieces of wood of the same species may differ in hardness and colour. One sample of sea water may contain more salt and different proportions of trace compounds than another. Detergent formulations differ

**Table 3.1 Electronic configuration of selected elements**

| <i>Element</i> | <i>Symbol</i> | <i>Atomic<br/>(proton)<br/>number</i> | <i>No. electrons<br/>in 1st shell</i> | <i>No. electrons<br/>in 2nd shell</i> | <i>No. electrons<br/>in 3rd shell</i> | <i>No. electrons in<br/>4th shell</i> |
|----------------|---------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Hydrogen       | H             | 1                                     | 1                                     |                                       |                                       |                                       |
| Helium         | He            | 2                                     | 2                                     |                                       |                                       |                                       |
| Lithium        | Li            | 3                                     | 2                                     | 1                                     |                                       |                                       |
| Beryllium      | Be            | 4                                     | 2                                     | 2                                     |                                       |                                       |
| Boron          | B             | 5                                     | 2                                     | 3                                     |                                       |                                       |
| Carbon         | C             | 6                                     | 2                                     | 4                                     |                                       |                                       |
| Nitrogen       | N             | 7                                     | 2                                     | 5                                     |                                       |                                       |
| Oxygen         | O             | 8                                     | 2                                     | 6                                     |                                       |                                       |
| Fluorine       | F             | 9                                     | 2                                     | 7                                     |                                       |                                       |
| Neon           | Ne            | 10                                    | 2                                     | 8                                     |                                       |                                       |
| Sodium         | Na            | 11                                    | 2                                     | 8                                     | 1                                     |                                       |
| Magnesium      | Mg            | 12                                    | 2                                     | 8                                     | 2                                     |                                       |
| Aluminium      | Al            | 13                                    | 2                                     | 8                                     | 3                                     |                                       |
| Silicon        | Si            | 14                                    | 2                                     | 8                                     | 4                                     |                                       |
| Phosphorus     | P             | 15                                    | 2                                     | 8                                     | 5                                     |                                       |
| Sulphur        | S             | 16                                    | 2                                     | 8                                     | 6                                     |                                       |
| Chlorine       | Cl            | 17                                    | 2                                     | 8                                     | 7                                     |                                       |
| Argon          | Ar            | 18                                    | 2                                     | 8                                     | 8                                     |                                       |
| Potassium      | K             | 19                                    | 2                                     | 8                                     | 8                                     | 1                                     |
| Calcium        | Ca            | 20                                    | 2                                     | 8                                     | 8                                     | 2                                     |
| Scandium       | Sc            | 21                                    | 2                                     | 8                                     | 9                                     | 2                                     |
| Titanium       | Ti            | 22                                    | 2                                     | 8                                     | 10                                    | 2                                     |
| Vanadium       | Va            | 23                                    | 2                                     | 8                                     | 11                                    | 2                                     |
| Chromium       | Cr            | 24                                    | 2                                     | 8                                     | 13                                    | 1                                     |
| Manganese      | Mn            | 25                                    | 2                                     | 8                                     | 13                                    | 2                                     |

between brands. It is possible to isolate the different chemical components from mixtures by physical means.

## Periodic table

The number of protons plus neutrons in an atom is termed the mass number. The number of protons (which also equals the number of electrons) is the atomic number. When elements are arranged in order of their atomic numbers and then arranged in rows, with a new row starting after each noble gas, the scheme is termed the periodic table. A simplified version is shown in Table 3.2.

The following generalizations can be made. Period 2 elements at the top of Groups I to VII tend to be anomalous. Atomic and ionic radii decrease across a period but increase down a group. Elements in a period have similar electronic configurations and those in groups have the same outer electronic arrangements. Elements at the top of a group tend to differ more from the succeeding elements in the group than they do from one another. Metals are on the left of the table and non-metals on the right. Elements such as silicon and germanium are borderline. Elements become less metallic on crossing a period and more metallic on descending a group. The Group I elements are alkali metals with reactivity increasing from top to bottom of the table. So the exothermic reaction of potassium (K) with water is more vigorous than that of lithium (Li).

Electronegativities increase across a period to a maximum with Group VII, the halogens, for which reactivity decreases from top to bottom of the table. Elements in Group 0 are unreactive

Table 3.2 Periodic table of the elements

| Group<br>Period           | I        | II       |                     |          |          |          |          |          |          |          |          |          | III      | IV        | V         | VI        | VII      | 0        |
|---------------------------|----------|----------|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------|-----------|----------|----------|
| <b>1</b>                  | H<br>1   |          |                     |          |          |          |          |          |          |          |          |          |          |           |           |           |          | He<br>2  |
| <b>2</b>                  | Li<br>3  | Be<br>4  |                     |          |          |          |          |          |          |          |          |          | B<br>5   | C<br>6    | N<br>7    | O<br>8    | F<br>9   | Ne<br>10 |
| <b>3</b>                  | Na<br>11 | Mg<br>12 | Transition elements |          |          |          |          |          |          |          |          |          | Al<br>13 | Si<br>14  | P<br>15   | S<br>16   | Cl<br>17 | Ar<br>18 |
| <b>4</b>                  | K<br>19  | Ca<br>20 | Sc<br>21            | Ti<br>22 | V<br>23  | Cr<br>24 | Mn<br>25 | Fe<br>26 | Co<br>27 | Ni<br>28 | Cu<br>29 | Zn<br>30 | Ga<br>31 | Ge<br>32  | As<br>33  | Se<br>34  | Br<br>35 | Kr<br>36 |
| <b>5</b>                  | Rb<br>37 | Sr<br>38 | Y<br>39             | Zr<br>40 | Nb<br>41 | Mo<br>42 | Tc<br>43 | Ru<br>44 | Rh<br>45 | Pd<br>46 | Ag<br>47 | Cd<br>48 | In<br>49 | Sn<br>50  | Sb<br>51  | Te<br>52  | I<br>53  | Xe<br>54 |
| <b>6</b>                  | Cs<br>55 | Ba<br>56 | *<br>57–71          | Hf<br>72 | Ta<br>73 | W<br>74  | Re<br>75 | Os<br>76 | Ir<br>77 | Pt<br>78 | Au<br>79 | Hg<br>80 | Tl<br>81 | Pb<br>82  | Bi<br>83  | Po<br>84  | At<br>85 | Rn<br>86 |
| <b>7</b>                  | Fr<br>87 | Ra<br>88 | **<br>89–102        |          |          |          |          |          |          |          |          |          |          |           |           |           |          |          |
| <b>*Lanthanide series</b> |          |          | La<br>57            | Ce<br>58 | Pr<br>59 | Nd<br>60 | Pm<br>61 | Sm<br>62 | Eu<br>63 | Gd<br>64 | Tb<br>65 | Dy<br>66 | Ho<br>67 | Er<br>68  | Tm<br>69  | Yb<br>70  | Lu<br>71 |          |
| <b>**Actinide series</b>  |          |          | Ac<br>89            | Th<br>90 | Pa<br>91 | U<br>92  | Np<br>93 | Pu<br>94 | Am<br>95 | Cm<br>96 | Bk<br>97 | Cf<br>98 | Es<br>99 | Fm<br>100 | Md<br>101 | No<br>102 |          |          |

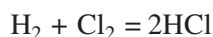
and termed ‘inert’, or ‘noble’, gases. Elements 21–30, 39–48 and 72–80 are termed ‘transition elements’ whilst those between 57 and 71 are termed ‘lanthanides’ or ‘rare earth’ elements, and elements 89–102 the ‘actinides’.

## Valency

Atoms combine to form molecules or compounds by linking together using chemical bonds. The number of bonds that elements are able to produce is termed their valency. Chemical changes are most conveniently represented by use of symbols and formulae in chemical equations. Atoms of each element are represented by a symbol. The chemical formula of a compound is merely a composite of its constituent atoms together with numerical indications of the ratio of the combining elements. If a number of atoms of one kind are present in a molecule the number is indicated by a subscript. So carbon dioxide is  $\text{CO}_2$ , ammonia  $\text{NH}_3$ , nitric acid  $\text{HNO}_3$  and ammonium nitrate is  $\text{NH}_4\text{NO}_3$ .

Chemical equations are used to describe reactions between compounds. The formulae of the reactants are written on the left-hand side of the equation and the formulae of the products on the right. If a number of molecules of one kind take part in the reaction the number is written as a coefficient in front of the formulae. The two sides of the equation must balance.

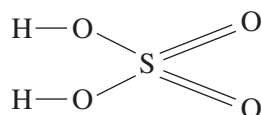
To illustrate, both hydrogen and chlorine have a valency of one. Elemental hydrogen consists of two hydrogen atoms linked to form a molecule of hydrogen written as  $\text{H}_2$ . Elemental chlorine comprises molecules of two atoms,  $\text{Cl}_2$ . One molecule of hydrogen can react with one molecule of chlorine to produce two molecules of hydrogen chloride:



Oxygen has a valency of two, nitrogen three and carbon four. Thus, elemental oxygen consists of molecules comprising two oxygen atoms. Because of their valencies, oxygen and hydrogen will co-react in a ratio of 1:2 respectively, i.e. one molecule of oxygen reacts with two molecules of hydrogen to form two molecules of water:



Whereas some atoms have only one valency, others have several, e.g. sulphur has valencies of two, four and six and can form compounds as diverse as hydrogen sulphide,  $\text{H}_2\text{S}$  (valency two), sulphur dioxide,  $\text{SO}_2$  (valency four) and sulphur hexafluoride,  $\text{SF}_6$  (valency six). Clearly some compounds comprise more than two different elements. Thus hydrogen, sulphur and oxygen can combine to produce sulphuric acid,  $\text{H}_2\text{SO}_4$ . From the structure it can be seen that hydrogen maintains its valency of one, oxygen two and sulphur is in a six valency state.



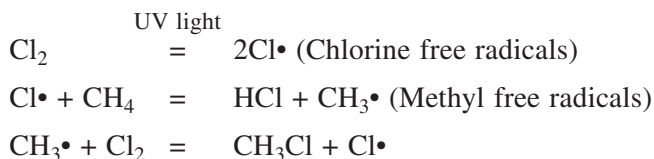
## Chemical bonds

Chemical bonds are strong forces of attraction which hold atoms together in a molecule. There are two main types of chemical bonds, viz. covalent and ionic bonds. In both cases there is a shift in the distribution of electrons such that the atoms in the molecule adopt the electronic configuration of inert gases.

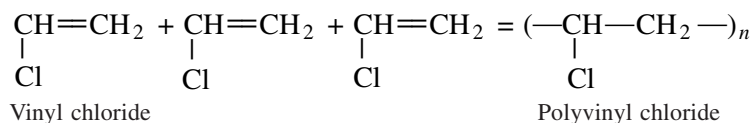
Ionic bonds are formed by the transfer of electrons between atoms. For example, calcium has two outer electrons, whilst chlorine has seven. By transfer of its two outer electrons, one to each chlorine atom, the calcium atom becomes doubly positively charged (a cation),  $\text{Ca}^{++}$ , and has the stable configuration of inert argon. The chlorine atoms each having gained an electron become negatively charged (an anion),  $2\text{Cl}^-$ , also with the stable configuration of argon. The negatively-charged chlorine atoms then become electrostatically attracted to the positively charged calcium ion to form calcium chloride,  $\text{CaCl}_2$ .

Covalent bonds form when non-metallic atoms combine by sharing, rather than transferring, electrons. This is achieved by overlapping of their electronic shells. The overlapping region attracts both atomic nuclei and bonds the atoms. For example, hydrogen atoms have one electron. In the hydrogen molecule each atom contributes one electron to the bond thereby allowing each hydrogen atom control of two electrons giving it the electron configuration of the inert gas helium. In a water molecule, the oxygen atom, with six outer electrons, gains control of an extra two electrons supplied by two atoms of hydrogen and gives it the configuration of the inert gas neon.

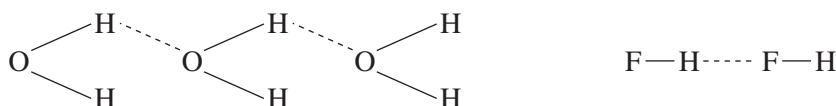
Bonds may also be broken symmetrically such that each atom retains one electron of the pair that formed the covalent bond. This odd electron is not paired like all the other electrons of the atom, i.e. it does not have a partner of opposite spin. Atoms possessing odd unpaired electrons are termed 'free radicals' and are indicated by a dot alongside the atomic or molecular structure. The chlorination of methane (see later) to produce methyl chloride ( $\text{CH}_3\text{Cl}$ ) is a typical free-radical reaction:



When many molecules combine the macromolecule is termed a polymer. Polymerization can be initiated by ionic or free-radical mechanisms to produce molecules of very high molecular weight. Examples are the formation of PVC (polyvinyl chloride) from vinyl chloride (the monomer), polyethylene from ethylene, or SBR synthetic rubber from styrene and butadiene.



Hydrogen bound covalently to nitrogen, oxygen or fluorine may bond with another atom of one of these elements by a unique linkage known as the 'hydrogen bond'. Since the hydrogen nucleus cannot control more than two electrons this is not a covalent bond but a powerful dipole-dipole interaction, traditionally indicated by dotted lines. It occurs in water, hydrofluoric acid, undissociated ammonium hydroxide and many hydrates, e.g.:



Hydrogen bonding accounts for the abnormally high boiling points of, e.g., water, hydrogen fluoride, ammonia, and many organic compounds (see later) such as alcohols.

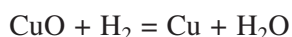
## Oxidation/Reduction

Processes which involve oxygen as reactant are termed oxidation reactions. Some are beneficial, e.g. the burning of fuels in the body to produce energy, the manufacture of chemical intermediates, e.g. cyclohexanone in the manufacture of nylon. Some are detrimental such as the oxidation of food to make it rancid: anti-oxidants are added to retard this. Compounds that give up oxygen easily or remove hydrogen from another compound are classed as oxidizing agents. They may comprise a gas, e.g. oxygen, chlorine, fluorine, or a chemical which releases oxygen, e.g. a nitrate or perchlorate. Thus copper becomes oxidized when it reacts with oxygen to form copper oxide:



Reactions which involve the use of hydrogen as a reactant are termed reductions, e.g. the addition of a molecule of hydrogen across the unsaturated  $\text{C}=\text{C}$  in olefins to produce saturated alkanes. The material which adds hydrogen, or removes oxygen, is termed the reducing agent.

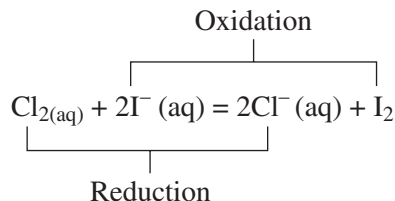
Clearly oxidation and reduction always occur together. The oxidation of copper by oxygen is accompanied by reduction of the oxygen to copper oxide. Similarly, whilst metal oxides such as  $\text{CuO}$ ,  $\text{HgO}$ ,  $\text{SnO}$  and  $\text{PbO}$  are reduced to the metal by hydrogen the latter becomes oxidized to water during the process:



The reactions are therefore termed redox reactions. Redox reactions can also be explained at the



electronic level. Thus, the conversion of atomic copper to the oxide produces  $\text{Cu}^{++}$  ions as copper atoms have lost electrons. The reduction of lead oxide by hydrogen entails removal of electrons from the oxide to produce neutral metallic lead. Oxidizing agents are therefore chemicals which attract electrons, and reducing agents chemicals that add electrons to an element or compound. Using these definitions the presence of either oxygen or hydrogen is not required, e.g. since chlorine is a stronger oxidizing agent than iodine it displaces iodine from iodides:



## Physical state

Chemicals exist as gases, liquids or solids. Solids have definite shapes and volume and are held together by strong intermolecular and interatomic forces. For many substances, these forces are strong enough to maintain the atoms in definite ordered arrays, called crystals. Solids with little or no crystal structure are termed amorphous.

Gases have weaker attractive forces between individual molecules and therefore diffuse rapidly and assume the shape of their container. Molecules can be separated by vast distances unless the gas is subjected to high pressure. Their volumes are easily affected by temperature and pressure. The behaviour of any gas is dependent on only a few general laws based upon the properties of volume, pressure and temperature as discussed in Chapter 4.

The molecules of liquids are separated by relatively small distances so the attractive forces between molecules tend to hold firm within a definite volume at fixed temperature. Molecular forces also result in the phenomenon of interfacial tension. The repulsive forces between molecules exert a sufficiently powerful influence that volume changes caused by pressure changes can be neglected i.e. liquids are incompressible.

A useful property of liquids is their ability to dissolve gases, other liquids and solids. The solutions produced may be end-products, e.g. carbonated drinks, paints, disinfectants or the process itself may serve a useful function, e.g. pickling of metals, removal of pollutant gas from air by absorption (Chapter 17), leaching of a constituent from bulk solid. Clearly a solution's properties can differ significantly from the individual constituents. Solvents are covalent compounds in which molecules are much closer together than in a gas and the intermolecular forces are therefore relatively strong. When the molecules of a covalent solute are physically and chemically similar to those of a liquid solvent the intermolecular forces of each are the same and the solute and solvent will usually mix readily with each other. The quantity of solute in solvent is often expressed as a concentration, e.g. in grams/litre.

Important common physical properties related to these states of matter are summarized in Table 3.3.

## Acids

Acids and bases (see later) are interrelated. Traditionally, acids are compounds which contain hydrogen and which dissociate in water to form hydrogen ions or protons,  $\text{H}^{+}$ , commonly written as:

**Table 3.3 Important common physical properties****Gas**

Density  
 Critical temperature, critical pressure (for liquefaction)  
 Solubility in water, selected solvents  
 Odour threshold  
 Colour  
 Diffusion coefficient

**Liquid**

Vapour pressure–temperature relationship  
 Density; specific gravity  
 Viscosity  
 Miscibility with water, selected solvents  
 Odour  
 Colour  
 Coefficient of thermal expansion  
 Interfacial tension

**Solid**

Melting point  
 Density  
 Odour  
 Solubility in water, selected solvents  
 Coefficient of thermal expansion  
 Hardness/flexibility  
 Particle size distribution/physical form, e.g. fine powder, flakes, granules, pellets, prills, lumps  
 Porosity



Examples include hydrochloric acid, nitric acid, and sulphuric acid. These are strong acids which are almost completely dissociated in water. Weak acids, such as hydrogen sulphide, are poorly dissociated producing low concentrations of hydrogen ions. Acids tend to be corrosive with a sharp, sour taste and turn litmus paper red; they give distinctive colour changes with other indicators. Acids dissolve metals such as copper and liberate hydrogen gas. They also react with carbonates to liberate carbon dioxide:



Both acids and alkalis are electrolytes. The latter when fused or dissolved in water conduct an electric current (see page 55). Acids are considered to embrace substances capable of accepting an electron pair. Mineral acids have wide usage as indicated by Table 3.4.

## Bases

Alkalis tend to be basic compounds which dissociate in water to produce hydroxyl ions,  $\text{OH}^-$  thus:



Specifically, an alkali is a hydroxide of one of the alkali or alkaline earth metals. Examples include the hydroxides of potassium, sodium, and calcium (where X is K, Na, and Ca, respectively).

**Table 3.4 Industrial uses of mineral acids**

| <i>Acid</i>                                       | <i>Main uses</i>                                                                                                      |
|---------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Hydrochloric acid (HCl)                           | Chemical manufacture, chlorine, food and rubber production, metal cleaning, petroleum well activation                 |
| Nitric acid (HNO <sub>3</sub> )                   | Ammonium nitrate production for fertilizers and explosives, miscellaneous chemical production                         |
| Phosphoric acid (H <sub>3</sub> PO <sub>4</sub> ) | Detergent builders and water treatment, foods, metal industries                                                       |
| Sulphuric acid (H <sub>2</sub> SO <sub>4</sub> )  | Alkylation reactions, caprolactam, copper leaching, detergents, explosives, fertilizers, inorganic pigments, textiles |
| Hydrofluoric acid (HF)                            | Etching glass                                                                                                         |

The first two are very soluble in water but the last is less so. Weaker bases include ammonium hydroxide where X is NH<sub>4</sub>. In fact every acid can generate a base by loss of a proton and the definition now includes any compound capable of donating electron pairs, e.g. amines. Bases turn litmus paper blue and show characteristic effects on other indicators. They are soluble in water, tarnish in air, and in concentrated form are corrosive to the touch. Common examples are given in Table 3.5.

**Table 3.5 Common bases**

| <i>Base</i>                                                           | <i>Properties</i>                                                                                                                                |
|-----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| Sodium hydroxide (NaOH)<br>(caustic soda)                             | White deliquescent solid. Sticks, flakes, pellets.<br>Dissolution in water is highly exothermic.<br>Strongly basic. Severe hazard to skin tissue |
| Potassium hydroxide (KOH)<br>(caustic potash)                         | White deliquescent solid. Sticks, flakes, pellets.<br>Dissolution in water is highly exothermic.<br>Strongly basic. Severe hazard to skin tissue |
| Calcium hydroxide (Ca(OH) <sub>2</sub> )<br>(slaked lime)             | White powder soluble in water yielding lime water. Alkaline                                                                                      |
| Ammonium hydroxide (NH <sub>4</sub> OH)<br>(aqueous ammonia solution) | Weakly alkaline. Emits ammonia gas. Severe eye irritant                                                                                          |

## Halogens

The halogens comprise fluorine, chlorine, bromine and iodine. They are remarkable for their similarity in chemical behaviour and for the gradation in physical properties. They are highly reactive and form covalent links with hydrogen, carbon, silicon, nitrogen, phosphorus, sulphur and oxygen, and with other halogen atoms. The halogen atoms also produce ionic bonds with metals. The elements tend to be toxic.

Fluorine is a greenish-yellow gas which condenses to a yellow liquid and pale yellow solid. It is the most chemically active of all the elements.

Chlorine (see page 280) is a heavy greenish-yellow gas with a choking smell. It combines directly with nearly all elements, exceptions being carbon, nitrogen and oxygen. It will react spontaneously with phosphorus, arsenic, antimony and mercury. Most metals will react with it when wet or on heating. It has a powerful affinity for hydrogen and will attack hydrocarbons.

Bromine is a dark red volatile liquid with a pungent odour. The vapour attacks the eyes and mucous membranes. It combines spontaneously and with deflagration with phosphorus, arsenic and potassium and with many other elements when warmed. It bleaches litmus and turns starch paper orange/yellow.

Iodine is a dark grey solid which is easily vaporized to a deep blue/violet vapour. It is sparingly soluble in water but dissolves in aqueous potassium iodide to give a brown solution. It combines directly with many elements.

## Metals

A metal is an electropositive element. There are over 70 metals in the earth's crust. Examples include copper, gold, iron, platinum, silver and tungsten. Chemically, in solution, a metal atom releases an electron to become a positive ion. In bulk metals are solids and tend to have high melting and boiling points (an exception is mercury). They are lustrous, relatively dense, malleable, ductile, cohesive and highly conductive to both electricity and heat.

Metals are crystalline in structure and the individual crystals contain positive metal ions. The outer valency electrons appear to be so loosely held that they are largely interspersed amongst the positive ions forming an electron cloud which holds the positive ions together. The mobility of this electron cloud accounts for the electrical conductivity. The crystal structure also explains the hardness and mechanical strength of metals whereas the elasticity is explained by the ability of the atoms and ions to slide easily over each other. Metals can be blended with other metals to produce alloys with specific properties and applications. Examples include:

Brass (alloy of copper and zinc) used for ship's propellers, screws, wind instruments.

Bronze (alloy of copper and tin) used for coins, medals, statues, church bells.

Duralumin (alloy of aluminium, magnesium, copper and manganese) used for structural purposes, e.g. in aircraft construction.

Nichrome (alloy of nickel, iron and chromium) used for heating elements.

Solder (alloy of tin and lead) used for joining metals, e.g. in electrical circuits.

Stellite (alloy of cobalt, tungsten, chromium, and molybdenum) used for surgical instruments.

(Variations in physical properties occur with changes in relative proportions.)

Group I metals are good conductors of heat and electricity and are so soft that they can be cut with a knife. As a result of their low specific gravities, Li, Na, and K float on water. They react vigorously with electronegative elements such as O, S and Cl. Indeed the ease with which the outer electron is detached from the atom explains their highly-reactive nature. This is exemplified by sodium which can only be handled if air is excluded, e.g. by nitrogen blanketing, or under vacuum, or submersed in oil.

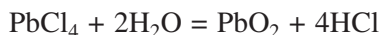
Group IIA metals include Be, Mg, Ca, Sr, Ba and Ra which are grey, moderately-hard, high melting-point substances. Like the alkali metals they attack water to liberate hydrogen but with less vigour. The salts of the alkaline earths are generally less stable towards heat and water than those of alkali metals, and less water soluble.

Group IIB includes Zn, Cd and Hg. Zinc has some resemblance to magnesium but the other metals in the group have little in common. At room temperature mercury is unaffected by air, water or non-oxidizing agents whereas zinc is more reactive, albeit tempered by a protective hydroxide film, a property utilized in galvanizing.

Compounds tend to be covalent. Metals form complex ions and their oxides are only weakly basic. Mercury forms no hydride.

Aluminium is an extremely light, white metal and whilst hard is malleable and ductile. On exposure to air the metal forms a protective oxide film which reduces its reactivity. Its compounds tend to be covalent in nature: the sulphate is hydrolysed in solution and the trichloride is volatile.

Both tin and lead from Group IV can form valency two and four compounds. Two of the four outer electrons can behave as inert when the atoms are bivalent. Bivalent tin (stannous) derivatives are covalent whereas the nitrate and sulphate of bivalent lead (plumbous) are ionic. Some tetravalent compounds such as the hydrides and chloride are unstable, e.g.:



Whereas stannic oxide is neither oxidizing nor reducing, plumbic oxide is a powerful oxidizer.

Tin finds widespread use because of its resistance to corrosion, or as foil or to provide protective coats/plates for other metals. Properties of lead which make industrial application attractive surround its soft, plastic nature permitting it to be rolled into sheets or extruded through dies. In the finely-divided state lead powder is pyrophoric; in bulk form the rapidly-formed protective oxide layer inhibits further reaction. It dissolves slowly in mineral acids. Industrial uses include roofing material, piping, and vessel linings, e.g. for acid storage.

The transition metals Cr, Mn, Fe, Co and Ni possess bi- and trivalent states. Chromium is a hard, malleable, white metal capable of high polish and does not tarnish in air. It is used for plating steel. Together with nickel it is also used in grades of stainless steel. Manganese is a grey metal which decomposes water and dissolves in dilute acids. Its chief use is in steel to remove trace quantities of oxygen and sulphur and to produce tough steel. Iron is a white, soft, malleable, ductile magnetic metal when pure and is used mainly in steel production. It is attacked by oxygen or steam to produce an oxide,  $\text{Fe}_3\text{O}_4$ . When exposed to ordinary atmospheric conditions it becomes covered with rust, i.e. hydrated ferric oxide,  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ . Cobalt does not oxidize in air at room temperature but oxidizes slowly if heated to yield cobaltous oxide,  $\text{CoO}$ . It dissolves slowly in acids becoming passive in concentrated nitric acid. Nickel is silver grey, hard, malleable, capable of high polish and resistant to attack by oxygen at room temperature but yields the oxide on heating. It dissolves in dilute nitric acid but is rendered passive by the concentrated acid. It forms the volatile, toxic tetra carbonyl with carbon monoxide.

The metals copper, silver and gold from Group IX are sometimes termed coinage metals. They possess characteristic metallic lustre, take high polish and resist attack by air. They are extremely malleable and ductile and excellent conductors of heat and electricity. All are attacked by chlorine; copper alone is attacked by oxygen. None of the metals displace hydrogen from acids. Copper has a characteristic red colour. It is used for cooking utensils and wires in telegraphs, telephones, power lines, and electrical machinery. Silver is a lustrous, white metal capable of high polish. It is tough, malleable, ductile and an efficient conductor of heat and electricity. Whilst resistant to attack by oxygen, on exposure to air it is slowly covered with a black film of silver sulphide. Uses include electroplating, mirrors, silverware, and crucibles. Gold is a yellow, malleable, ductile metal which does not tarnish in air and is inert to any mineral acid. It reacts with halogens and aqua-regia (a mixture of hydrochloric and nitric acids in the ratio of 4:1).

## Oxygen and sulphur

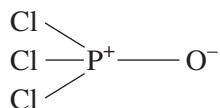
Oxygen is the first member of Group VI with six electrons in the outer shell. It is a colourless, tasteless and odourless gas which condenses to a blue liquid and freezes to a blue solid under

cryogenic conditions (discussed in Chapter 8). The oxygen atom exerts covalent, ionic, or co-ionic characteristics. The principle types of compounds are those in which the oxygen atom

exerts two ionic bonds by accepting two electrons from the same or different atoms, e.g.  $\text{Ca}^{++}\text{O}^-$ ;

exerts two covalent bonds by sharing electron pairs, e.g.  $\text{H}_2\text{O}$ ;

exerts co-ionic character by combining with another atom which already has the inert configuration but of which at least one pair of electrons is unshared, e.g.



Thus oxygen can feature in a wide variety of compounds including ozone, oxides, water, hydrogen peroxide, carbonates, nitrates/nitrites, etc. It comprises about 21% of normal air (by volume).

Sulphur molecules are  $\text{S}_8$  and it can exist in several forms. Its compounds are more acidic than those of oxygen and it may assume covalency up to six. It forms a series of oxides and oxyacids of diverse chemistry. Combustion yields mainly  $\text{SO}_2$ , a cause of atmospheric pollution from sulphur-bearing fossil fuels.

## Nitrogen, phosphorus, arsenic and antimony

None of these elements from Group V form cations of the type  $\text{N}^{++++}$  due to loss of all five valency electrons. All the elements are strongly electronegative and readily form covalent bonds with other elements.

Nitrogen is a colourless, tasteless, odourless gas which is slightly soluble in water (see also page 296). It is non-toxic and inert and comprises about 79% of normal air (by volume). It neither burns nor supports combustion and at room temperature does not react with any substance. On heating, however, it combines with oxygen to produce nitric oxide  $\text{NO}$ , with hydrogen to produce ammonia  $\text{NH}_3$ , and with silicon to form silane  $\text{SiH}_4$ , with calcium carbide to form calcium cyanamide  $\text{CaCN}_2$  and with metals such as lithium, calcium, barium, magnesium and aluminium to form the corresponding nitrides.

Phosphorus exists as white and red phosphorus. The former allotrope may be preserved in the dark at low temperatures but otherwise reverts to the more stable red form. The white form is a waxy, translucent, crystalline, highly-toxic solid subliming at room temperature and inflaming in air at 35 °C, so it is handled under water. The red form is a reddish violet crystalline solid which vaporizes if heated at atmospheric pressure and condenses to give white phosphorus. The red form ignites in air at 260 °C. Both are insoluble in water, and white phosphorus can be stored beneath it. Phosphorus forms a host of compounds such as phosphine, tri- and penta-halides, tri-, tetra- and penta-oxides, oxyacids including hypophosphorous, orthophosphorous and orthophosphoric acids.

Arsenic exists as grey, yellow and black forms of differing physical properties and susceptibilities towards atmospheric oxygen. The general chemistry is similar to that of phosphorus but whereas phosphorus is non-metallic, the common form of arsenic is metallic. Traces of arsenides may be present in metallic residues and drosses; these may yield highly toxic arsine,  $\text{AsH}_3$ , with water.

Antimony is a bluish white metal with good lustre but poor heat conducting ability. It is stable in air and resistant to dilute acids but attacked by halogens, sulphur, phosphorus and arsenic.

## pH

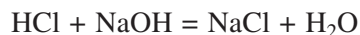
The strength of acids and bases is measured on a pH (potential of hydrogen) scale:

$$\text{pH} = -\log_{10} [\text{H}^+]$$

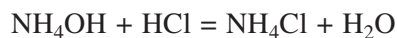
The hydrogen ion concentration of a normal solution of a strong acid is about 1 gram-ion per litre and that of a typical strong base is  $10^{-14}$  gram-ion per litre. Because of the vast range of possible concentrations it is convenient to use a logarithmic scale to express the hydrogen ion concentration of a solution. The symbol pH is used to denote the degree of acidity of a solution. Pure water which dissociates slightly to produce  $10^{-7}$  gram-ions of  $\text{H}^+$  per litre is taken as the standard of neutrality. Thus water has a pH of 7. Solutions of pH less than 7 are acidic and those greater than 7 are alkali. The pH of a solution can be determined electrically using a hydrogen or glass electrode and reference electrode (e.g. calomel electrode) or by chemical indicators. The pH scale is shown in Figure 5.1.

## Salts

Acids and alkalis react with each other to produce salts and water, e.g.:



Thus salts are compounds formed by replacement of hydrogen in an acid by a metal. Clearly non-metals can also be involved, e.g.:



Salts are non-volatile and in the fused state or in solution conduct an electric current. Many salts are hydrated in the solid state with water of crystallization.

These reactions are exothermic and must be carefully controlled if the reactants are concentrated, since the rates can be very rapid.

## Organic chemistry

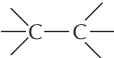
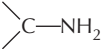
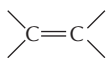
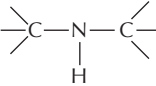
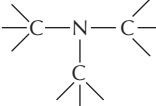
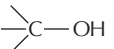
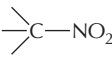
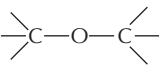
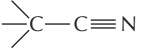
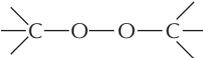
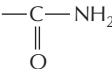
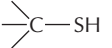
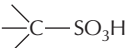
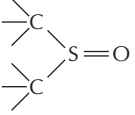
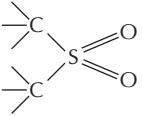
Carbon is in the same group in the periodic table as silicon, germanium, tin and lead. The electronic structures are characterized by the presence of four electrons in the external quantum shell. The elements, however, do not form ions of the type  $\text{X}^{++++}$  and compounds are covalent in the quadrivalent state. Lead and tin may be bivalent when lead forms ionic valencies. Carbon differs from the other elements in this group by forming an enormous range of compounds, the chemistry of which is a special discipline, organic chemistry. There are over a million known organic compounds, including sugar, starch, alcohol, resins and mineral oil. The versatility of carbon arises from:

the stability of the compounds produced whether from electropositive elements such as hydrogen, or from electronegative elements such as oxygen or fluorine;

the ability of carbon to covalently link with other carbon atoms with one, two or three bonds, e.g.  $\text{H}_3\text{C}-\text{CH}_3$  (ethane),  $\text{H}_2\text{C}=\text{CH}_2$  (ethylene),  $\text{HC}\equiv\text{CH}$  (ethyne, or acetylene). These links may be in the form of chain or ring skeletons. Compounds comprising mainly carbon and hydrogen are termed hydrocarbons.

Tables 3.6 and 3.7 illustrate some of the key organic groupings. For convenience organic compounds can be classified as either aliphatic or aromatic.

**Table 3.6 Examples of aliphatic organic structures**

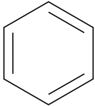
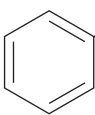
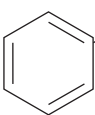
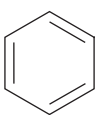
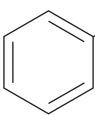
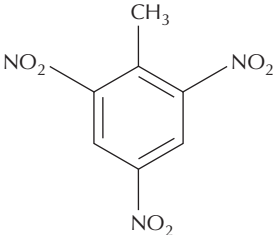
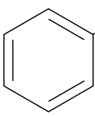
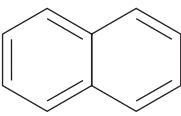
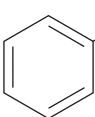
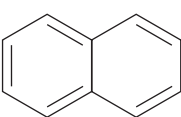
| Carbon-carbon groups                                                                |               | Carbon-nitrogen groups                                                              |                      |
|-------------------------------------------------------------------------------------|---------------|-------------------------------------------------------------------------------------|----------------------|
|    | Paraffin      |    | Primary amine        |
|    | Olefin        |    | Secondary amine      |
|    | Acetylene     |    | Tertiary amine       |
| Carbon-oxygen groups                                                                |               | Carbon-sulphur groups                                                               |                      |
|    | Alcohol       |    | Nitro                |
|    | Ether         |    | Nitrile (or cyanide) |
|  | Peroxide      |    | Amide                |
|  | Ketone        |  | Mercaptan            |
|  | Acyl chloride |  | Sulphonic acid       |
|  | Aldehyde      |  | Sulfoxide            |
|  | Fatty acid    |  | Sulphone             |

### *Aliphatic compounds*

Aliphatic compounds are straight chain or acyclic compounds and are characterized by addition and free-radical chemistry.



Table 3.7 Selected aromatic compounds

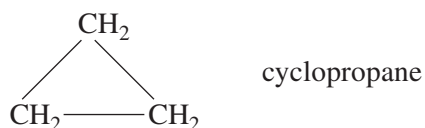
|                                                                                    |                            |                                                                                    |                             |
|------------------------------------------------------------------------------------|----------------------------|------------------------------------------------------------------------------------|-----------------------------|
|   | Benzene                    |   | Hydroxy benzene<br>(Phenol) |
|   | Amino benzene<br>(Aniline) |   | Methyl benzene<br>(Toluene) |
|   | Benzoic acid               |   | Trinitro toluene<br>(TNT)   |
|   | Benzene sulphonic acid     |   | Naphthalene                 |
|  | Chlorobenzene              |  | Beta naphthylamine          |

## Carbon/carbon compounds

### Paraffins

Compounds containing only carbon and hydrogen are termed paraffins or alkanes. The general formula for these compounds is  $C_nH_{2n+2}$  where  $n$  is an integer. When only single bonds are present between carbon atoms they are classified as 'saturated'. Examples include, ethane, propane, and butane; the last two are common fuel gases:

|                       |         |                                               |
|-----------------------|---------|-----------------------------------------------|
| $CH_4$                | methane | (natural gas)                                 |
| $CH_3-CH_3$           | ethane  |                                               |
| $CH_3-CH_2-CH_3$      | propane | } commonly used as<br>liquefied petroleum gas |
| $CH_3-CH_2-CH_2-CH_3$ | butane  |                                               |

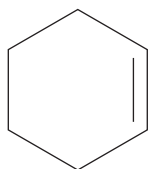


The alkanes are almost insoluble in water, sodium hydroxide and sulphuric acid but soluble in non-polar solvents. The liquid density increases as the size of the paraffin molecule increases but tends to level off at 0.8, i.e. all alkanes are less dense than water; therefore they will float and spread as thin films on water. The boiling points and melting points increase as the number of carbon atoms rises. The physical properties of cyclic aliphatic hydrocarbons resemble those of the straight-chain counterparts, although the boiling points and densities of the cyclic compounds are somewhat higher. The strong carbon-carbon and carbon-hydrogen bonds render paraffins relatively unreactive and the few reactions they undergo require forcing conditions and tend to produce mixtures. On heating between 400 and 600 °C they can undergo thermal degradation or 'cracking' to produce simpler alkanes, olefins and hydrogen; this can increase the flammable hazards.

### *Olefins*

When carbon atoms are linked by a double bond the compounds are called olefins. Since these molecules contain less than the maximum quantity of hydrogen they are termed unsaturated. Examples include ethylene, propylene, and butylene. Note that the latter can exist in several forms:

|                                                 |              |
|-------------------------------------------------|--------------|
| $\text{CH}_2=\text{CH}_2$                       | ethylene     |
| $\text{CH}_3\text{CH}=\text{CH}_2$              | propylene    |
| $\text{CH}_3-\text{CH}_2-\text{CH}=\text{CH}_2$ | 1-butylene   |
| $\text{CH}_3-\text{CH}=\text{CH}-\text{CH}_3$   | 2-butylene   |
| $(\text{CH}_3)_2\text{C}=\text{CH}_2$           | iso-butylene |



cyclohexene

Their physical properties are essentially those of the alkanes. It is the unsaturated linkages that dominate the chemistry and the main reaction is one of addition (e.g. hydrogen, halogen, and hydrogen halides) across the double bond to produce saturated compounds. This reactivity is utilized in the manufacture of long-chain polymers, e.g. polyethylene and polypropylene.

### *Acetylenes*

Compounds with even less hydrogen to carbon than olefins are acetylenes or alkynes as exemplified by:

|                                                 |           |
|-------------------------------------------------|-----------|
| $\text{HC}\equiv\text{CH}$                      | acetylene |
| $\text{CH}_3\text{C}\equiv\text{CH}$            | propyne   |
| $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$ | 1-butyne  |
| $\text{CH}_3\text{C}\equiv\text{CCH}_3$         | 2-butyne  |

Physical properties are similar to alkanes and the chemistry is dictated by the carbon triple bond. This bond is less reactive than the olefin double bond towards electrophilic reagents, but more

reactive towards chemicals that are themselves electron rich. Some metals, e.g. copper, react to form metal acetylides. If allowed to dry out the heavy metal acetylides are prone to explode (Chapter 7).

### *Carbon/Halogen compounds*

One or several hydrogen atoms in hydrocarbons can be substituted by halogen to produce alkyl halides. This significantly alters the toxicity, e.g. substitution of a chlorine atom in a hydrocarbon leads to an increase in the potential narcotic and anaesthetic effects. Because of the increased molecular weight, alkyl halides have considerably higher boiling points than the corresponding hydrocarbon. For a given alkyl group the boiling point increases with increasing atomic weight of halogen, with fluorides having the lowest boiling point and iodides the highest. Increasing the halogen content also reduces the ease with which some compounds undergo chemical or biological oxidation and hence they can accumulate in the environment. Some halogenated organic substances react with ozone in the upper atmosphere and deplete the planet of this gas which provides a protective shield against harmful ultra-violet light.

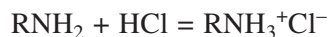
Some alkyl halides are toxic, e.g. trichloromethane or chloroform ( $\text{CHCl}_3$ ) and tetrachloromethane or carbon tetrachloride ( $\text{CCl}_4$ ). Progressive chlorination of hydrocarbons gives liquids and/or solids of increasing non-flammability, density, viscosity, solvent power and decreasing specific heat, dielectric constant and water solubility. So perchloroethylene,  $\text{CCl}_2=\text{CCl}_2$ , is a common dry-cleaning solvent and trichloroethylene,  $\text{CHCl}=\text{CCl}_2$ , is widely used in vapour degreasing of metal components. Despite being polarized molecules they are insoluble in water.

As with other groups, halogens can substitute hydrogen in organic compounds containing additional functional moieties such as carboxylic acids to form acid chlorides, e.g. acetyl chloride  $\text{CH}_3\text{COCl}$ . These are reactive acidic compounds liberating hydrochloric acid on contact with water.

### *Carbon/Nitrogen compounds*

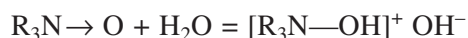
Of the organic compounds of sufficient basicity to turn litmus paper blue amines are the most significant. These compounds have trivalent nitrogen bonded directly to carbon by single bonds with the general formula  $\text{RNH}_2$ ,  $\text{R}_2\text{NH}$  or  $\text{R}_3\text{N}$  where R is an alkyl or aryl group. The first are classed as primary amines, the next secondary amines and the last tertiary amines. The chemistry is influenced by the number of hydrogen atoms attached to the nitrogen.

Amines, like ammonia  $\text{NH}_3$ , are polar compounds and, except for tertiary amines, form intermolecular hydrogen bonds leading to higher boiling points than non-polar compounds of the same molecular weight, but lower boiling points than alcohols or acids. The smaller molecules, containing up to about six carbon atoms, dissolve in water. Aliphatic amines are similar in basicity to ammonia and form water-soluble salts with acids:



Nitriles, or alkyl cyanides, are compounds in which carbon is bound to nitrogen by triple bonds. They tend to be stable, neutral substances with pleasant smells and are less toxic than hydrogen cyanide. The smallest compounds are water soluble liquids and all are soluble in organic solvents.

Tertiary amines can be oxidized to form amine oxides in which the amino nitrogen atom is linked to a single oxygen atom. The resulting compounds are basic dissolving in water thus:

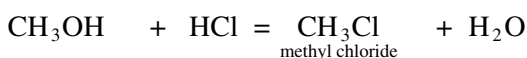
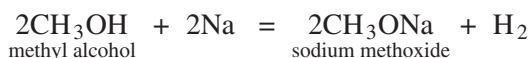


When nitrogen linked to two oxygen atoms is bound to carbon the compounds are termed

nitroparaffins. When pure these compounds are colourless liquids with pleasant smells. They are sparingly soluble in water and most can be distilled at atmospheric pressure. The lower members are used as solvents for oils, fats, cellulose esters, resins, and dyes. Nitroparaffins are also used as raw materials for the synthesis of other chemicals such as pesticides, drugs, explosives, fuels (e.g. nitromethane in drag racing fuel). Some nitroparaffins are explosive as described in Chapter 7.

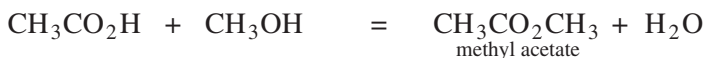
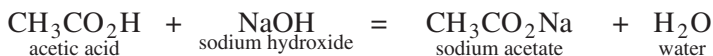
### Carbon/Oxygen compounds

Compounds containing oxygen linked to a carbon and a hydrogen atom are termed alcohols. Simple examples are methyl and ethyl alcohol,  $\text{CH}_3\text{OH}$  and  $\text{C}_2\text{H}_5\text{OH}$ , respectively. Reactions of alcohols are characterized by the replacement of either the OH hydrogen atom or the entire OH group:



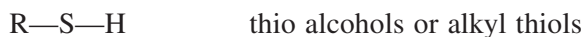
Compounds in which oxygen bridges two carbon atoms are termed ethers, e.g. diethyl ether,  $\text{CH}_3\text{CH}_2\text{—O—CH}_2\text{CH}_3$ . This is used as a solvent and an anaesthetic. Generally, ethers are unreactive compounds but on standing they can react with atmospheric oxygen to produce explosive peroxides, e.g. diethyl peroxide,  $\text{CH}_3\text{CH}_2\text{—O—O—CH}_2\text{CH}_3$ .

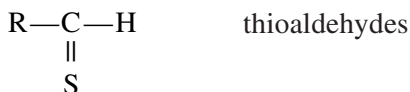
Oxygen can link solely to carbon atoms by double bonds to form carbonyl compounds containing the  $\text{C=O}$  group. If the same carbonyl group is linked to another carbon the compounds are classed as ketones, if connected to a hydrogen atom they are aldehydes, and if connected to OH groups they are carboxylic acids. The  $\text{C=O}$  carbon can also be bonded to other atoms such as halogens, nitrogen and sulphur. The carbonyl group tends to dominate the chemistry of aldehydes and ketones since it can be oxidized to carboxylic acids, reduced to alcohols or undergo addition reactions. Carboxylic acids are acidic in nature, typically reacting with bases to form salts or with alcohols to produce often sweet-smelling esters:



### Carbon/Sulphur compounds

Since sulphur is in the same group as oxygen in the periodic table it replaces oxygen in organic structures to produce 'thio' analogues such as:





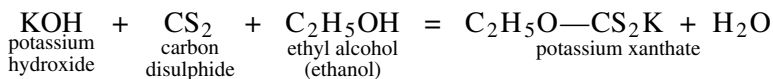
With the exception of methanethiol, which is a gas, thiols are colourless, evil-smelling liquids. Their boiling points are lower than those of the corresponding alcohols, reflecting their reduced association and degree of hydrogen bonding between hydrogen and sulphur. For the same reason thiols are less water soluble than their oxygen counterparts. The chemistry of thiols resembles that of alcohols but they are more acidic, reflecting the stronger acidity of hydrogen sulphide over water, of which alcohols can be regarded as alkyl derivatives. They are used as feedstocks in rubber and plastics industries and as intermediates in agricultural chemicals, pharmaceuticals, flavours and fragrances. Because they react with rubber-containing materials selection of hose and gasket material is crucial.

Alkyl sulphides are the sulphur analogues of ethers from which they differ considerably in chemistry. They are unpleasant-smelling oils, insoluble in water but soluble in organic solvents. They tend to be comparatively inert. Mustard gas,  $\text{ClCH}_2\text{CH}_2-\text{S}-\text{CH}_2\text{CH}_2\text{Cl}$ , an oily liquid boiling at 216 °C with a mustard-like smell, is highly poisonous and a vesicant, and for this reason found use in chemical warfare.

Alkyl sulphoxides occur widely in small concentrations in plant and animal tissues. No gaseous sulphoxides are known and they tend to be colourless, odourless, relatively unstable solids soluble in water, ethyl alcohol and ether. They are freely basic, and with acids form salts of the type  $(\text{R}_2\text{SOH})^+ \text{X}^-$ . Because sulphoxides are highly polar their boiling points are high. Their main use is as solvents for polymerization, spinning, extractions, base-catalysed chemical reactions and for pesticides.

Thioketones and aldehydes readily polymerize to the trimer and isolation of the monomer is difficult.

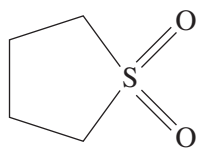
Thioacids have a most disagreeable odour and slowly decompose in air. Their boiling points are lower than those of the corresponding oxygen counterparts and they are less soluble in water, but soluble in most organic solvents. An important dithioacid is dithiocarbonic acid ( $\text{HO}-\text{CS}_2\text{H}$ ). Whilst the free acid is unknown, many derivatives have been prepared such as potassium xanthate giving a yellow precipitate of copper xanthate with copper salts:



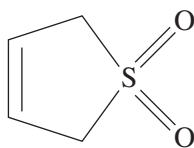
Unlike oxygen, sulphur can exist in higher valency states and as a result can be incorporated into organic structures in additional ways. Examples include:



Sulphones are colourless, very stable, water-soluble solids that are generally resistant to reduction. The most important sulphones are sulfolane (1) and sulfolene (2):



(1)



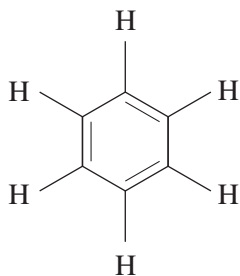
(2)

Compound 1 is used as a solvent in the food, paint, resin/plastics, soap and woodpulp/paper industries, and as a plasticizer. Compound 2 is used as an intermediate for the manufacture of hydraulic fluid additives and cosmetics. Sulphonal (2:2-bis(ethylsulphonyl)-propane), another important sulphone, is a colourless solid, stable to acids and alkalis, with hypnotic properties.

Sulphonic acids are water soluble, viscous liquids. Their acidity is akin to that of sulphuric acid; they form salts with bases but fail to undergo esterification with alcohols. Their properties vary according to the nature of R: some are prone to thermal decomposition. They are used as surfactants and in the dye industry; some have biological uses. 2-Amino-ethanesulphonic acid is the only naturally occurring sulphonic acid.

### Aromatic compounds

Aromatic compounds are benzene and its derivatives and compounds that resemble benzene in their behaviour in a chemistry dominated by ionic substitution. Benzene has the formula  $C_6H_6$  commonly written as the ring:



In reality all carbon atoms share equally the pool of electrons which constitute the double bonds and benzene resists addition across the double bonds which would otherwise destroy its unique structure and stability. Single or multiple hydrogen atoms can be substituted to form a host of derivatives containing similar functional groups to those above, e.g. saturated and unsaturated aliphatic chains, amino, carboxylic acidic, halogeno, nitro, and sulphonic acid groups as shown in Table 3.6.

Aromatic compounds find wide industrial use as exemplified by Table 3.8.

Benzene and alkylbenzenes possess low polarity with similar physical properties to hydrocarbons. They are insoluble in water but soluble in non-polar solvents such as ether. They are less dense than water (Table 6.1) and boiling points rise with increasing molecular weight (ca 20–30 °C increment for each carbon atom). Since melting point depends not only on molecular weight but also on molecular shape, the relationship to structure is more complicated. Benzene itself is a colourless liquid boiling at 80 °C and freezing at 5.4 °C. It is highly flammable with a flash point of –11 °C but with a narrow flammable range of 1.4–8%. It is acutely toxic producing narcotic effects comparable to toluene but it also poses chronic effects on bone marrow which may lead to anaemia or even leukaemia. Similar effects are not proven for pure toluene, but in the past commercial toluol was contaminated with benzene.

**Table 3.8 Industrial uses of selected aromatic compounds**

| <i>Compound</i>                                             | <i>Use</i>                                                                                                                                           |
|-------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Aniline (amino benzene)<br>$C_6H_5NH_2$                     | Agrochemicals, dyes and pigments, pharmaceuticals, photographic chemicals, polymers, rubbers                                                         |
| Benzene<br>$C_6H_6$                                         | Production of ethyl benzene, cumene, cyclohexane, maleic anhydride, nitrobenzene, chlorobenzene, detergents                                          |
| Benzene (and alkylbenzene) sulphonic acids<br>$C_6H_5SO_3H$ | Detergents, phenols, dyes                                                                                                                            |
| Benzoic acid<br>$C_6H_5CO_2H$                               | Alkyl resins, chemical intermediate, oil drilling additive, medicines                                                                                |
| Nitro benzene<br>$C_6H_5NO_2$                               | Production of aniline, para-aminophenol, and dyes                                                                                                    |
| Phenol (hydroxy benzene)<br>$C_6H_5OH$                      | Phenolic resins as adhesives and for the car industry, caprolactam                                                                                   |
| Toluene (methyl benzene)<br>$C_6H_5CH_3$                    | Automotive fuels additive, organic solvent, production of benzene, styrene, and terephthalic acid                                                    |
| Styrene (vinyl benzene)<br>$C_6H_5CH=CH_2$                  | Polymers $(C_8H_8)_n$ for audio and video cassettes, carpet backing, domestic appliances, packaging, food containers, furniture, toys, vehicle parts |
| Xylenes (di methyl benzene)<br>$C_6H_4(CH_3)_2$             | Plasticizers, polymer fibres and resins, solvents                                                                                                    |

## Combustion chemistry

In biological systems the oxidation of fuels by oxygen is a fundamental reaction by which energy is created, along with by-products such as water and carbon dioxide:

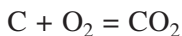


Anything that interferes with this mechanism in humans can result in reduced well-being or even death. Silicosis or asbestosis may impair oxygen transport from lungs to blood. Inhaled carbon monoxide may combine with haemoglobin and prevent it from carrying oxygen. Waste products may not be removed efficiently when kidney function is damaged by toxic chemicals such as mercury and phenolic substances. Fuels such as glucose may be prevented from entering cells due to inactivation of the necessary catalytic enzymes by, e.g., toxic metals or fluoracetate.

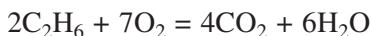
The oxidation of fuels is common outside living systems, combustion being the extreme example. Combustion is a chemical reaction between a fuel and usually oxygen, with the liberation of energy often as heat. A flame is produced when sufficient energy is liberated, usually in the visible range of the spectrum though some are in the infra-red or ultra-violet region and invisible. Chemical combustion processes are initiated by heat, light, sparks, etc. As the temperature of the combustible substance rises it reaches the ignition temperature specific to the material and to the pressure, and the combustion process begins. It spreads from the ignition source to the adjacent layer of gaseous mixture of fuel and oxidant (usually oxygen in air). In turn the burning layer ignites the next layer until equilibrium is reached between the total heat energies of reactants and products when the combustion process ceases. When the rate of heat lost from the mass is less

than the heat liberated by the combustion process an explosion occurs. When combustion increases progressively such that the flame front advances supersonically, compression from the shockwave causes an increase in temperature and self-ignition of the fuel, i.e. detonation. The requirements for chemicals to burn are discussed in Chapter 6.

Most organic materials will burn; the smaller molecules may be highly flammable. In the simplest form carbon (e.g. charcoal) in the presence of a surplus of oxygen will produce carbon dioxide:

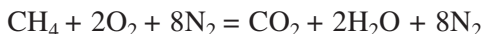


Usually, however, fuels are hydrocarbons and the products of combustion can be complex and depend upon the nature of the fuel, the amount of oxygen present, and the temperature. A great deal of energy is required to break carbon-carbon and carbon-hydrogen bonds such as the high temperatures of flames. Once the energy barrier is surmounted the subsequent chain of events proceeds readily with the evolution of energy, often sufficient to keep the combustion reaction in progress. Simple hydrocarbons in excess oxygen will produce carbon dioxide and water:



If nitrogen or sulphur is present in the fuel then the mixture of combustion products may include oxides of these elements. In the absence of excess oxygen incomplete oxidation occurs to produce partially oxidized carbon compounds such as aldehydes, ketones, phenols, and carbon monoxide. Carbon monoxide is extremely toxic and some of the other compounds are respiratory irritants.

Since air comprises about 21% oxygen and 79% nitrogen, with traces of other gases, e.g.  $\text{CO}_2$ , complete combustion of methane (i.e. natural gas) in air can be represented as:



This demonstrates how the oxygen is depleted resulting, as summarized in Chapter 6, in an irrespirable atmosphere rich in nitrogen. High temperature combustion may also result in the generation of oxides of nitrogen,  $\text{NO}_x$ , which are respiratory irritants.

Under certain conditions some inorganic materials will burn. Magnesium metal as powder or ribbon when heated to its melting point in oxygen burns to produce magnesium oxide, and in air to produce a mixture of magnesium oxide and magnesium nitride. Aluminium also burns in air at high temperatures to produce a mixture of the oxide and nitride. Dust explosion characteristics of various inorganic materials are included in Table 6.1.

Some materials such as oil-impregnated cotton and iron pyrites are prone to spontaneous combustion, whilst selected materials such as metal alkyls and metals in a finely divided state burn on immediate contact with water or air. These are termed 'pyrophoric'. Examples and precautions for their control are described in Chapter 6.

Dangers arising from fires therefore include:

Burns from heat radiation, or fire engulfment.

Asphyxiation due to consumption of oxygen until the concentration is <18%.

Poisoning from toxic combustion products. In chemical fires, particularly those involving mixtures, an extremely complex mixture of gases and particulates, e.g. smoke may be produced. The composition depends upon the initial compounds involved, the temperatures attained and the oxygen supply, and is hence often unpredictable. Some gaseous compounds may derive from thermal breakdown, i.e. pyrolysis, of the chemicals rather than oxidation as illustrated in Tables 3.9 and 3.10.

Injury from collapse of weakened structures.

Explosions (see Chapter 6).



## Chemical reactivity

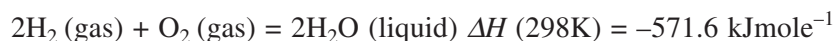
### Enthalpy

Energy cannot be created or destroyed but is converted from one form to another. Thermodynamics is the study of energy transfer during reactions and on the work done by chemical systems. It defines the energy required to start a reaction or the energy given out during the process. This change in energy is denoted  $\Delta U$ . During chemical reactions energy may be absorbed or liberated. If this is in the form of heat, and since most reactions are performed at constant pressure, this is termed enthalpy and denoted by  $H$ . The enthalpy change (or heat of reaction) is:

$$\Delta H = H_2 - H_1$$

where  $H_1$  is the enthalpy of reactants and  $H_2$  the enthalpy of the products (or heat of reaction).

When  $H_2$  is less than  $H_1$  the reaction is exothermic and  $\Delta H$  is negative, i.e. temperature increases. When  $H_2$  is greater than  $H_1$  the reaction is endothermic and the temperature falls. The heat of reaction is usually expressed in the equation as  $\Delta H$ , e.g.



Data exist for the enthalpy of chemical reactions, formation of substances from their constituent elements, combustion, fusion, neutralization, solution, vaporization, etc.

### Electrochemistry

When strips of reactive metals such as zinc are placed in water a potential difference, the electromotive force (emf), is set up; the metal becomes negatively charged due to the transfer of zinc ions to the solution and the build-up of electrons on the metal. The metal strips or rods are termed the

**Table 3.9** Classes of pyrolysis products produced during fires

| <i>Chemical type involved in a fire</i> | <i>Pyrolysis product</i>                                                                                               |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Halogenated plastic                     | Polyaromatic hydrocarbons<br>Aliphatics<br>Substituted benzenes<br>Halogenated aliphatics<br>Dioxins and furans        |
| Non-halogenated plastics                | Polycyclic aromatic compounds<br>Aliphatics<br>Substituted benzenes<br>Heavy metals                                    |
| Halogenated chemicals                   | Polycyclic aromatic hydrocarbons<br>Aliphatics<br>Substituted benzenes<br>Halogenated aliphatics<br>Dioxins and furans |
| Non-halogenated chemicals               | Polycyclic aromatic hydrocarbons<br>Aliphatics<br>Substituted benzenes                                                 |
| Metal-based pesticides                  | Range of organics<br>Heavy metals                                                                                      |

electrode and the potential difference is termed the electrode potential. The latter depends upon the identity of the metal, the temperature and the concentration of metal ions in solution. Thus copper is less reactive than zinc so that if the two metals are immersed in water and connected by a wire electrons will flow through the external circuit from Zn (cathode) to Cu (anode). The process is termed electrolysis and the arrangement by which chemical energy is converted into

**Table 3.10 Compounds liberated from a range of materials during fires**

| Fire material                     |                                  | CO  | HCN | HCl | P <sub>2</sub> O <sub>5</sub> | Isocyanate | Irritants,<br>e.g.<br>acrolein | HF<br>and<br>HBr | PAHs | NO <sub>x</sub> |
|-----------------------------------|----------------------------------|-----|-----|-----|-------------------------------|------------|--------------------------------|------------------|------|-----------------|
| Chlorine                          | Emissions<br>On-site<br>Off-site | NA  | NA  | NA  | NA                            | NA         | NA                             | NA               | NA   | NA              |
| Oil refineries<br>(storage tanks) | Emissions                        | +   | –   | –   | –                             | –          | ++                             | –                | +++  | –               |
|                                   | On-site                          | –   | –   | –   | –                             | –          | ++                             | –                |      | –               |
|                                   | Off-site                         | –   | –   | –   | –                             | –          | +                              |                  |      |                 |
| Paints and<br>solvents            | Emissions                        | +++ | –   | ++  | +                             | ++         | ++                             | –                | ++   | –               |
|                                   | On-site                          |     | –   | +   | –                             | ++         | +                              | –                |      | –               |
|                                   | Off-site                         | –   | –   | –   | –                             | +          | –                              | –                | –    | –               |
| Petrol                            | Emissions                        | ++  | –   | –   | –                             | –          | ++                             | –                | +    | –               |
|                                   | On-site                          | –   | –   | –   | –                             | –          | +                              | –                |      | –               |
|                                   | Off-site                         | –   | –   | –   | –                             | –          | –                              | –                | –    | –               |
| Phosphorus                        | Emissions                        | +++ | –   | +   | +++                           | ++         | ++                             | –                | ++   | –               |
|                                   | On-site                          |     | –   | +   | ++                            | ++         | +                              | –                |      | –               |
|                                   | Off-site                         | –   | –   | –   | +                             | +          | –                              | –                | –    | –               |
| Plastics                          | Emissions                        | +++ | +++ | +++ | +                             | ++         | ++                             | +                | ++   | ++              |
|                                   | On-site                          |     |     | ++  | –                             | ++         | ++                             |                  |      | +               |
|                                   | Off-site                         | –   | –   | +   | –                             | +          | +                              | –                |      | –               |
| Resins and<br>adhesives           | Emissions                        | +++ | ++  | +   | –                             | ++         | ++                             | +                | ++   | ++              |
|                                   | On-site                          |     |     | +   | –                             | ++         | ++                             |                  |      | +               |
|                                   | Off-site                         | –   | –   | –   | –                             | +          | +                              | –                | –    | –               |
| Rubber                            | Emissions                        | +++ | +   | +   | –                             | –          | +++/>++                        | –                | ++   | +               |
|                                   | On-site                          |     |     | +   | –                             | –          | ++/>+                          | –                |      |                 |
|                                   | Off-site                         | –   | –   | –   | –                             | –          | +                              | –                | –    | –               |
| Upholstery<br>(polyurethane)      | Emissions                        | +++ | +++ | +++ | –                             | ++         | ++                             | +                | ++   | ++              |
|                                   | On-site                          |     |     | ++  | –                             | ++         | ++                             |                  |      | +               |
|                                   | Off-site                         | –   | –   | +   | –                             | +          | +                              | –                | –    | –               |
| Vegetation<br>(forests)           | Emissions                        | +   | –   | –   | –                             | –          | +                              | –                | +    | +               |
|                                   | On-site                          | –   | –   | –   | –                             | –          | +                              | –                |      |                 |
|                                   | Off-site                         | –   | –   | –   | –                             | –          | –                              | –                | –    | –               |
| Waste tips                        | Emissions                        | –   | +   | +   | –                             | +          | ++                             | +                | +    | +               |
|                                   | On-site                          | –   |     | +   | –                             | +          | +                              |                  |      |                 |
|                                   | Off-site                         | –   | –   | –   | –                             | –          | –                              | –                | –    | –               |

#### Key

|           |                                                          |
|-----------|----------------------------------------------------------|
| NA        | Not applicable since chlorine is the main risk           |
| Emissions | Total emissions during a fire                            |
| On-site   | Exposure of workers and emergency service personnel      |
| Off-site  | Exposure of the general public and the wider environment |
| –         | Zero or little emission or exposure                      |
| +         | Likely to be some emission or exposure                   |
| ++        | Likely to be low level emission or exposure              |
| +++       | Likely to be greatest emission or exposure               |

electrical energy is termed a 'chemical' or 'galvanic cell'. To standardize conditions emfs are determined at 25 °C of cells containing a molar metallic electrode (i.e. a rod of metal immersed in a solution containing 1 gram-ion of the metallic ion per litre) opposed to a molar hydrogen electrode (i.e. a plate of platinum covered with a thin film of hydrogen to simulate a rod of hydrogen).

The ease with which an atom gains or loses electrons is termed the electronegativity of the element. Tabulation of the elements in order of ease by which they lose electrons is called the electrochemical series and is shown in Table 6.10. Chapter 4 explains the importance of this to the formation and control of corrosion, and Chapter 6 discusses the relevance to predicting reactivity of metals towards water and their potential to become pyrophoric.

Other industrial applications of electrolysis include extraction/purification of metals from ores, electroplating, and the manufacture of certain chemicals such as sodium hydroxide. In the latter, sodium chloride solution when electrolysed is converted to sodium hydroxide to produce chlorine at the anode and hydrogen at the cathode. Both of these gaseous by-products are collected for industrial use; chlorine is used in the production of bleach and PVC; hydrogen is used as a fuel, to saturate fats, and to make ammonia.

### ***Rates of chemical reaction***

Whereas thermodynamics describes the energy requirements of a reaction, the speed at which it progresses is termed kinetics. It is important to be able to control the rate of chemical reactions for commercial and safety reasons. If a reaction takes too long to progress the rate at which a product is manufactured would not be viable. Alternatively, if reactions progress too fast and 'runaway' out of control there could be dangers such as explosions. The rate at which reactions take place can be affected by the concentration of reactants, pressure, temperature, wavelength and intensity of light, size of particles of solid reactants, or the presence of catalysts (i.e. substances which alter the speed of reactions without being consumed during the reaction) or impurities. Catalysts tend to be specific to a particular reaction or family of reactions. Thus nickel is used to facilitate hydrogenation reactions (e.g. add hydrogen to C=C double bonds) whereas platinum is used to catalyse certain oxidation reactions. Sometimes care is needed with the purity of reactants since impurities can act as unwanted catalysts; alternatively, catalysts can be inactivated by 'poisoning'.

The effect of temperature on different types of reaction is shown in Figure 7.5.

For reactions which progress slowly at room temperature it may be necessary to heat the mixture or add a catalyst for the reaction to occur at an economically-viable rate. For very fast reactions the mixture may need to be cooled or solvent added to dilute the reactants and hence reduce the speed of reaction to manageable proportions. In general the speed of reaction

- doubles for every 10 °C rise in temperature;
- is proportional to the concentration of reactants in solution;
- increases with decreased particle size for reactions involving a solid;
- increases with pressure for gas phase reactions.

Chapter 4 discusses reaction kinetics further.

# Physicochemistry

Hazards from processes using chemicals are assessed on the basis of:

|                              |                                                                                                                                                                             |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Inherent chemical properties | Toxic, flammable/explosive, reactive, unstable                                                                                                                              |
| Chemical form                | Liquid, solid (briquette, flake, powder), gas, vapour, air-borne particulate (including mist, fume, froth, aerosol, dust)                                                   |
| Quantity                     | In storage, held up in process stages, in the working atmosphere, as wastes, etc.                                                                                           |
| Processing conditions        | Use of high or low temperature, high pressure, vacuum or possible hazardous reactions (polymerization, oxidation, halogenation, hydrogenation, alkylation, nitration, etc.) |

Hazards can often be foreseen from basic physicochemical principles, as summarized below.

## Vapour pressure

The vapour pressure of a chemical provides an indication of its volatility at any specific temperature. As an approximation, the vapour pressure  $p'$  of a pure chemical is given by

$$\log_e p' = (A/T) + B$$

where  $A$  and  $B$  are empirically determined constants and  $T$  is the absolute temperature.

Hence the vapour pressure of a chemical will increase markedly with temperature.

For a component 'a' in a mixture of vapours, its partial pressure  $p_a$  is the pressure that would be exerted by that component at the same temperature if present alone in the same volumetric concentration. So with a mixture of two components, 'a' and 'b', the total pressure is

$$P = p_a + p_b$$

If an inert gas is also present, its pressure is additive:

$$P = p_a + p_b + p_{\text{inert}}$$

In an 'ideal mixture' the partial pressure  $p_a$  is proportional to the mole fraction  $y_a$  of the component in the gas phase:

$$p_a = y_a P$$

and this partial pressure is also related to the concentration in the liquid phase expressed as mole fraction  $x_a$  by:

$$p_a = p'_a x_a$$

where  $p'_a$  is the vapour pressure of component 'a' at the prevailing temperature. So, if all the components are miscible in the liquid phase the total pressure  $P$  of a mixture is

$$P = p'_a x_a + p'_b x_b + p'_c x_c$$

As a result:

The flash point of any flammable liquid will be lowered if it is contaminated with a more volatile, flammable liquid.

Application of heat to a flammable liquid (e.g. due to radiation or flame impingement in a fire, or because of 'hot work') can generate a flammable vapour–air mixture.

Increase in temperature of a toxic liquid can create an excessive concentration of toxic vapour in air. This may occur as the result of an exothermic reaction.

The pressure in the vapour space of an incompletely full, sealed vessel containing liquid cannot be reduced by partially draining off liquid.

The pressure in an incompletely full container of liquid will increase with temperature and can, in the extreme, result in rupture due to over-pressurization unless adequate relief is provided. (This may occur following an uncontrolled exothermic reaction.) Alternatively, partial ejection of the contents can occur on opening.

The composition of the vapour in equilibrium with a miscible liquid mixture at any temperature, e.g. on heating during distillation, will be enriched by the more volatile components. The composition of the liquid phase produced on partial condensation will be enriched by the less volatile components. Such 'fractionation' can have implications for safety in that the flammability and relative toxicity of the mixtures can change significantly.

## Gas–liquid solubility

For a dilute solution, the partial pressure exerted by a dissolved liquid (a solute) 'a' in a liquid solvent is given by

$$p_a = Hx_a$$

where  $H$  is Henry's law constant for the system and  $x_a$  is the mole fraction of solute. A different value of  $H$  is applicable to each gas–liquid system.

As a result:

The solubility of a gas generally decreases with any increase in temperature. So, if a solution in a closed receptacle is heated above the filling temperature during transport or storage, loss of gas can result on opening or liquid discharge.

With a 'sparingly-soluble' gas a much-higher partial pressure of that gas is in equilibrium with a solution of a given concentration than is the case with a highly soluble gas.

Exposure of a solution to any atmosphere will lead to the take-up, or release, of gas until equilibrium is eventually attained.

Rapid absorption of a gas in a liquid in an inadequately-vented vessel can result in implosion, i.e. collapse inwards due to a partial vacuum.

## Liquid-to-vapour phase change

Evaporation of liquid to form vapour is accompanied by a considerable increase in volume. For example, at atmospheric pressure one volume of water will generate 1600 volumes of steam. Similarly 4.54 litres of gasoline will yield 0.93 m<sup>3</sup> of neat vapour on complete vaporization. The reverse process, condensation, is accompanied by a considerable – and often rapid – decrease in volume. As a result:

Contact of water with molten metals or salts or hot oil (above 100 °C at atmospheric pressure) can result in a ‘steam explosion’, or a ‘boil-over’, with ejection of process materials. Similar effects occur with other volatile liquids.

Evaporation of a relatively-small volume of liquid in an enclosed space can produce a flammable or toxic vapour hazard. Leakage, or spillage, of a chemical maintained as a liquid above its atmospheric boiling point by pressure (e.g. liquefied petroleum gases) or as a liquid by refrigeration (e.g. ammonia) can result in a sizeable vapour cloud.

Sudden cooling of a vapour-filled vessel which is sealed, or inadequately vented, may cause an implosion due to condensation to liquid.

Cooling of vapour in a vented vessel may cause sucking-back of process materials or ingress of air.

Vaporization in enclosed containers can produce significant pressure build-up and explosion.

In addition to volume changes the effect of temperature is also important. Thus the specific latent heat of vaporization of a chemical is the quantity of heat, expressed as kJ/kg, required to change unit mass of liquid to vapour with no associated change in temperature. This heat is absorbed on vaporization so that residual liquid or the surroundings cool. Alternatively an equivalent amount of heat must be removed to bring about condensation. Thus the temperature above a liquefied gas is reduced as the liquid evaporates and the bulk liquid cools. There may be consequences for heat transfer media and the strength of construction materials at low temperatures.

## Solid-to-liquid phase change

The phase change of a chemical from solid to liquid generally results in an expansion in volume. (Ice to water is one exception.) As a result:

Ejection of liquid can occur from open pipelines when solid blockages are released by external heating, e.g. by steam. (This hazard is increased if pressure is applied upstream of the constriction.)

Melting of solid in a sealed system may exert a significant internal pressure.

## Density differences of gases and vapours

As an approximation, at constant pressure,

$$\text{density of a gas/vapour} \propto \frac{\text{relative molecular mass}}{\text{absolute temperature}}$$

Since few chemicals (e.g. hydrogen, methane, ammonia) have a molecular weight less than that

**Table 4.1** Densities of some toxic gases and vapours relative to air at 20 °C

|                          | <i>Density gas/<br/>density of air</i> | <i>Relative<br/>molecular mass</i> |
|--------------------------|----------------------------------------|------------------------------------|
| Bromine vapour           | 5.54                                   | 160                                |
| Phosgene                 | 3.43                                   | 99                                 |
| Chlorine                 | 2.46                                   | 71                                 |
| Sulphur dioxide          | 2.22                                   | 64                                 |
| Acrylonitrile vapour     | 1.84                                   | 53                                 |
| Hydrogen cyanide vapour  | 0.94                                   | 27                                 |
| Hydrogen fluoride vapour | 0.69                                   | 20                                 |
| Ammonia                  | 0.59                                   | 17                                 |

of air, under ambient conditions most gases or vapours are heavier than air. For example, for common toxic gases refer to Table 4.1; for flammable vapours refer to Table 6.1. At constant pressure the density of a gas or vapour is, as shown, inversely proportional to the absolute temperature. As a result:

On release, vapours heavier than air tend to spread (i.e. to ‘slump’) at low level and will accumulate in pits, sumps, depressions in ground, etc. This may promote a fire/explosion hazard, or a toxic hazard, or cause an oxygen-deficient atmosphere to form, depending on the chemical.

Heavy vapour can remain in ‘empty’ vessels after draining out liquid and venting via the top with similar associated hazards.

On release, vapours which are less dense than air at ambient temperature may tend to spread at low level when cold (e.g. vapour from liquid ammonia or liquefied natural gas spillages). Gases less dense than air may rise upwards through equipment, or buildings, and if unvented will tend to accumulate at high level. This is an important consideration with piped natural gas which tends to diffuse upwards from fractured pipes, open valves or faulty appliances. Hydrogen from leakages in use, e.g. from cylinders (refer to Table 9.12), or from electrolytic processes, e.g. battery-charging, rapidly diffuses upwards.

Hot gases rise by thermal lift. Hence in the open air they will disperse. Within buildings this is a serious cause of fire escalation and toxic/asphyxiation hazards if smoke and hot gases are able to spread without restriction (or venting) to upper levels.

A balanced flue can serve to effectively vent a combustion process in a gas-fired appliance, but must be sound in construction and unrestricted to avoid leaks.

Once a gas or vapour has been mixed with air, it is the mean density of the mixture which is important (similar considerations arise when mixing other gases). The mean density of a gas mixture is given by:

$$p_{\text{mixture}} = \frac{p_g V_g + p_a V_a}{V_g + V_a}$$

where  $V_g$ ,  $V_a$  are the volumes of gas and air, and  $p_g$ ,  $p_a$  the densities of gas and air respectively. Clearly if  $V_a$  is large relative to  $V_g$ , or if  $p_g$  does not differ significantly from  $p_a$ , the value of  $p_{\text{mixture}}$  approximates to  $p_a$ . As a result:

The density of air saturated with a chemical vapour may not differ significantly from that of air itself. Refer to Table 4.2. This is an important consideration when designing ventilation systems, i.e. both high- and low-level extract vents may be desirable.

**Table 4.2** Relative densities of air saturated with selected chemicals at 25 C

|                      | <i>Relative density of saturated air<br/>(air at 25 C)</i> |
|----------------------|------------------------------------------------------------|
| Benzene              | 1.21                                                       |
| Bromochloromethane   | 1.07                                                       |
| Carbon tetrachloride | 1.65                                                       |
| Diisobutyl ketone    | 1.01                                                       |
| Nitroethane          | 1.04                                                       |
| Parathion            | 1.0                                                        |

## Density differences of liquids

The specific gravities (s.g.) of liquid chemicals vary widely, e.g. for the majority of hydrocarbon fuels s.g. <1.0 but for some natural oils and fats, chlorinated hydrocarbons, s.g. >1.0. Density is generally reduced by any increase in temperature. As a result:

On heating up, thermal expansion of a liquid in sealed piping, equipment or a container may exert sufficient hydraulic pressure to cause rupture or failure. (Hence specific filling ratios are followed with containers, e.g. road tankers.)

A lighter liquid can spread over and, if immiscible, remain on top of a denser liquid. Thus liquid fuels and many organic liquids will spread on water; this may result in a hazard in sumps, pits or sewerage systems and often precludes the use of water as a jet in fire-fighting. Stratification of immiscible liquids may occur in unagitated process or storage vessels.

## Immiscible liquid–liquid systems

In a combination of two immiscible liquids, each exerts its own vapour pressure independently. The total pressure is then the sum of the vapour pressures,

$$P = p'_a + p'_b$$

Also if a solute C is present in solvent A when it is mixed with solvent B, some transfer will occur of C to B. Eventually equilibrium will be attained between the concentrations of C in each phase. For many dilute solutions this is expressed by

$$y = mx$$

where  $x$  is the mass (or mole) fraction of C in A,  $y$  is the mass (or mole) fraction of C in B and  $m$  is the partition coefficient. In concentrated solutions the equilibria are better represented by a distribution curve. As a result of these equilibria:

The boiling point of a mixture of immiscible liquids can be significantly lower than that of either chemical, so violent boiling may occur unexpectedly on mixing them whilst hot.

Partition of solute into a second immiscible liquid (e.g. water) may result in its release if the latter is subsequently exposed to air, e.g. in a sump or effluent drain.

Trace contamination of an immiscible liquid can occur following accidental contact with another liquid even if the mutual solubilities are considered insignificant.



## Vapour flashing

If a liquid near its boiling point at one pressure is 'let down' to a reduced pressure, vapour flashing will occur. This will cease when the liquid temperature is reduced, due to removal of the latent heat of vaporization, to a temperature below the saturation temperature at the new pressure.

As a result:

Flashing of vapour containing entrained mist may occur on venting equipment or vessels containing volatile liquids. This may create a toxic or flammable hazard depending on the chemical; with steam the risk is of scalding. Rupture of equipment can produce a similar effect. Escapes or spillages of liquefied petroleum gas, or chlorine or ammonia, rapidly generate a vapour cloud.

Loss of containment, e.g. due to a crack or open valve, from beneath the liquid level in a liquefied gas vessel is potentially more serious than if it occurs from the gas space because the mass flowrate is greater.

Absorption of heat (auto-refrigeration) and consequent temperature reduction on flashing may have a serious effect on associated heat transfer media, upon the strength of materials of construction, and result in frosting at the point of leakage. Exposure of personnel carries a risk of frostbite.

## Effects of particle or droplet size

Airborne particulate matter may comprise liquid (aerosols, mists or fogs) or solids (dust, fumes). Refer to Figure 5.2. Some causes of dust and aerosol formation are listed in Table 4.3. In either case dispersion, by spraying or fragmentation, will result in a considerable increase in the surface area of the chemical. This increases the reactivity, e.g. to render some chemicals pyrophoric, explosive or prone to spontaneous combustion; it also increases the ease of entry into the body. The behaviour of an airborne particle depends upon its size (e.g. equivalent diameter), shape and density. The effect of particle diameter on terminal settling velocity is shown in Table 4.4. As a result:

All combustible solids can create a dust explosion hazard if dispersed in air as a fine dust within certain concentration limits. Refer to Table 6.2. The hazard increases with decreasing particle size.

Particles in the respirable size range, i.e. about 0.5–7  $\mu\text{m}$ , will, once dispersed, remain airborne for extended periods. Indeed since they are sensitive to slight air currents they may be permanently suspended.

A dust cloud comprising a distribution of particle sizes soon fractionates, e.g. visible matter settles to the ground in a few minutes. Hence the size distribution of airborne particles may differ significantly with time and from that of the source material. (This is particularly relevant to occupational hygiene measurements involving toxic dust emissions.)

## Surface area effects in mass transfer or heterogeneous reactions

The rate of mass transfer across a phase boundary or interface can be expressed by

$$N = K_s A (\Delta C)_m$$

**Table 4.3 Selected sources of dusts and aerosols**

| <i>Particulate form</i> | <i>Common sources</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dust</b>             | Crushing<br>Grinding<br>Milling<br>Sieving<br>Drying, e.g. spray, drum, fluidized bed drying<br>Powder mixing<br>Emptying bags of powder, or fines from bag filters<br>Powder transfer, e.g. conveyors<br>Brushing<br>Buffing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Aerosol</b>          | Droplet generation by air pressure differential across the film, e.g. bursting of liquid film in bubbles, froth across bottle mouths and pipette tips<br>Formation of froth by mixing of gas and liquid in shake cultures, fermenters or test tubes<br>Forceful ejection of the contents of pipettes or syringe, especially if already containing gas bubbles<br>Vibration or twanging of hypodermic needles or platinum loops<br>Impact of a droplet on a liquid, e.g. from liquid falling under gravity<br>Separation of two moist surfaces, e.g. withdrawal of the plunger in a syringe barrel or stopper from a tube<br>Centrifugal forces, e.g. escape of liquid from a centrifuge<br>Sizzling, e.g. when a platinum loop or inoculation tool is flamed or plunged hot into liquid<br>Deliberate atomization in some humidification operations, gas scrubbing, spray drying, spray painting<br>Leakage of liquids transferred under pressure, e.g. from flange joints, pump glands<br>Misting during condensation (e.g. in distillations) gas absorption, vaporizations<br>Use of propellants, e.g. hand-held aerosol cans<br>Electrolytic processes<br>Rapid liquid discharge from an orifice, e.g. shower heads, taps |

**Table 4.4 Terminal velocities of particles of different sizes**

| <i>Diameter</i><br>( $\mu\text{m}$ ) | <i>Rate of fall</i><br>(m/s) |
|--------------------------------------|------------------------------|
| 5000                                 | 9                            |
| 1000                                 | 4                            |
| 500                                  | 3                            |
| 100                                  | $3 \times 10^{-1}$           |
| 50                                   | $75 \times 10^{-3}$          |
| 10                                   | $3 \times 10^{-3}$           |
| 5                                    | $75 \times 10^{-5}$          |
| 1                                    | $36 \times 10^{-6}$          |
| 0.5                                  | $10 \times 10^{-6}$          |
| 0.1                                  | $36 \times 10^{-8}$          |

(Particle density 1000 kg/m<sup>3</sup>; air at 20 °C, 100 kPa.)

where  $N$  is mass transferred/unit time

$K$  is a mass transfer coefficient

$A$  is the interfacial area

$(\Delta C)_m$  is the mean concentration gradient, representing the deviation from equilibrium. Hence the rate is directly related to coefficient  $K$ , which will generally increase with any increase in turbulence such as increased relative velocity between the phases or agitation; to the exposed surface area  $A$ ; and to the concentration difference, whether it is a pressure or humidity differential or a solubility relationship. As a result:

The rate of evolution of a toxic or flammable vapour from a liquid (e.g. in an open vessel, from a spillage or as a spray) is directly related to the exposed area. Therefore, the rate of vapour formation from solvent-impregnated rag, from solvent-based films spread over a large area, from foams or from mists can be many times greater than that from bulk liquid.

All gas absorption processes are surface area dependent. Hence water fog may be an effective means of dealing with emissions of soluble gases, e.g. ammonia or hydrogen fluoride.

The rates of gas–solid reactions are surface area dependent, so finely-divided metals, coal etc. may be prone to oxidation leading to spontaneous combustion. A combustible dust will burn much more rapidly than the bulk solid, and if dispersed in air cause a dust explosion (refer to Table 6.2).

The rates of gas–liquid reactions are surface area dependent. Hence in the spontaneous combustion of oil impregnating fibrous thermal insulation on hot equipment, oxidation is facilitated by the large exposed surface area and, since the dissipation of heat is restricted, the temperature can rise until the oil ignites spontaneously.

The important factors, on exposure to chemicals that are toxic by absorption via the skin, are the contact area and the duration of exposure (refer to Table 13.8).

## Enthalpy changes on mixing of liquids

Mixing of two or more chemicals which have dissimilar molecular structures may be exothermic (liberating heat) or endothermic (absorbing heat). As a result:

Unless controlled, the enthalpy release when some liquids are mixed may result in their ejection from equipment or, in the extreme, an explosion.

## Critical temperatures of gases

Every gas has a critical temperature above which it cannot be liquefied by the application of pressure alone. The critical pressure is that required to liquefy a gas at its critical temperature. Data for common gases are given in Table 4.5. As a consequence:

Liquefied gases may be stored fully refrigerated, with the liquid at its bubble point at near atmospheric pressure; fully pressurized, i.e. at ambient temperature; or semi-refrigerated with the temperature below ambient but the vapour pressure above atmospheric pressure. Of the gases listed in Table 4.6, all those with critical temperatures below ambient must be maintained under refrigeration to keep them in the liquid phase.

**Table 4.5 Critical temperature and pressure data for common gases**

|                 | <i>Critical<br/>Temperature (°C)</i> | <i>Critical<br/>pressure (bar)</i> |
|-----------------|--------------------------------------|------------------------------------|
| Water (steam)   | 374                                  | –                                  |
| Sulphur dioxide | 157                                  | 219                                |
| Chlorine        | 144                                  | 78                                 |
| Ammonia         | 132                                  | 77.7                               |
| Nitrous oxide   | 39                                   | –                                  |
| Carbon dioxide  | 31.1                                 | 73.1                               |
| Oxygen          | –119                                 | 50                                 |
| Nitrogen        | –147                                 | 33.7                               |
| Hydrogen        | –240                                 | 12.9                               |

If the temperature remains constant, the pressure within any cylinder containing liquefied gas will remain constant as gas is drawn off (i.e. more liquid simply evaporates) so the quantity of gas remaining cannot be deduced from the pressure.

**Table 4.6 Gases commonly stored in liquefied form**

| <i>Gas</i>                                 | <i>Boiling point<br/>at 1 bar abs.<br/>(°C)</i> | <i>Liquid density<br/>at boiling<br/>point<br/>(kg/m<sup>3</sup>)</i> | <i>Volume ratio gas<br/>(1 bar abs., 20°C)<br/>to liquid<br/>(at boiling point)</i> | <i>Vapour<br/>pressure<br/>at 38°C<br/>(bar abs.)</i> | <i>Critical<br/>temperature<br/>(°C)</i> |
|--------------------------------------------|-------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------|------------------------------------------|
| <b>Can be stored without refrigeration</b> |                                                 |                                                                       |                                                                                     |                                                       |                                          |
| Ethylene oxide                             | 11                                              | 883                                                                   | 425                                                                                 | 2.7                                                   | 195                                      |
| <i>n</i> -Butane                           | 0                                               | 602                                                                   | 242                                                                                 | 3.6                                                   | 152                                      |
| Butadiene (1, 3)                           | –4                                              | 650                                                                   | 280                                                                                 | 4.1                                                   | 152                                      |
| Butylene (α)                               | –6                                              | 626                                                                   | 262                                                                                 | 4.3                                                   | 146                                      |
| Isobutane                                  | –12                                             | 595                                                                   | 241                                                                                 | 5.0                                                   | 135                                      |
| Ammonia                                    | –33                                             | 682                                                                   | 962                                                                                 | 14.6                                                  | 133                                      |
| Propane                                    | –42                                             | 582                                                                   | 315                                                                                 | 13.0                                                  | 97                                       |
| Propylene                                  | –48                                             | 614                                                                   | 347                                                                                 | 15.7                                                  | 92                                       |
| <b>Requires refrigeration</b>              |                                                 |                                                                       |                                                                                     |                                                       |                                          |
| Ethane                                     | –89                                             | 546                                                                   | 436                                                                                 | –                                                     | 32                                       |
| Ethylene                                   | –104                                            | 568                                                                   | 487                                                                                 | –                                                     | 9                                        |
| Methane (LNG)                              | –162                                            | 424                                                                   | 637                                                                                 | –                                                     | –82                                      |
| Oxygen                                     | –183                                            | 1140                                                                  | 860                                                                                 | –                                                     | –119                                     |
| Nitrogen                                   | –196                                            | 808                                                                   | 696                                                                                 | –                                                     | –147                                     |

## Chemical reaction kinetics

The rate of chemical reaction is generally a function of reactant concentration and temperature. For many homogeneous reactions therefore, if they are exothermic,

$$\text{rate of generation} \propto e^{RT_r}$$

where  $R$  is the gas constant and  $T_r$  is the absolute temperature. If the heat is removed by forced convection to a coolant in a jacket or coil,

$$\text{rate of removal} \propto T_r - T_a$$

where  $T_a$  is the coolant temperature. Thus:

Since the generation rate is exponential whereas the removal rate is linear, for any exothermic reaction in a specific reactor configuration a critical condition may exist, i.e. a value of  $T_r$  beyond which 'runaway' occurs.

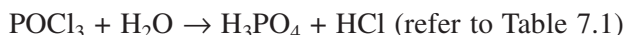
A reaction which is immeasurably slow at ambient temperature may become rapid if the temperature is raised.

With some reactions which have a significant rate at ambient temperature, e.g. catalysed reactions, oxidations or self-polymerization of certain polymers, severe hazards may be associated with an elevation in temperature.

Exothermic reactions require control strategies which may involve temperature control, dilution of reagents, controlled addition of one reagent, containment/venting and provision for emergencies. Refer to p. 248.

Many liquid phase or heterogeneous solid-liquid or gas-liquid reactions result in gaseous products or byproducts. These products may be toxic (refer to Table 5.1) or flammable (refer to Table 6.1), or result in overpressurization of any sealed container or vessel. Unless pressure relief is provided, relatively small volumes of reactants – the presence of which may not be expected – may generate sufficient gas pressure to rupture a container. The causes of pressure build-up may be:

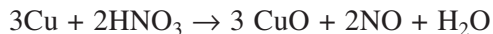
Reactions with water, e.g. reaction of phosphorus oxychloride with water to produce gaseous hydrogen chloride:



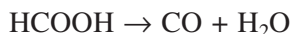
Electrolytic corrosion (see later).

Reaction due to contaminants, e.g. in reusable containers or in transfer pipelines.

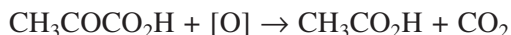
Reaction with construction materials, e.g. nitric acid can produce nitric oxide gas on contact with copper in pipes or copper windings in motors of canned pumps:



Slow decomposition of a chemical of limited stability. For example, the slow decomposition of 98–100% formic acid to gaseous carbon monoxide in a full 2.5 litre bottle would produce 7 bar pressure during one year at 25 °C if unvented:



Self-initiated reactions, e.g. pyruvic acid on storage can become oxidized by air (or airborne yeasts) to form sufficient gaseous carbon dioxide to overpressurize the container:



Pyruvic acid should therefore be stored refrigerated with light and air excluded.

The precautions required can be any combination of those in Table 4.7.

## Corrosion

Pure metals and their alloys interact gradually with the elements of a corrosive medium to form stable compounds and the resulting metal surface is considered to be 'corroded'. The corrosion reaction comprises an anode and an electrode between which electrons flow. Table 6.10 shows the

**Table 4.7 Precautions applicable to reactions producing gaseous products or byproducts**


---

|                                                                                                                |
|----------------------------------------------------------------------------------------------------------------|
| Temperature control                                                                                            |
| Adequately sized pressure relief                                                                               |
| Elimination of contaminants, including metallic residues, from process streams and equipment                   |
| Selection of materials of construction compatible with the chemical(s) in use, properly cleaned and passivated |
| Elimination of ingress of reactive chemicals, e.g. water, air                                                  |
| Date labelling and inventory control in storage                                                                |
| Cleaning and inspection of reusable containers, tankers etc, before refilling                                  |

---

anodic–cathodic series, or electrochemical series, for selected metals and for hydrogen (since the discharge of hydrogen ions takes place in most corrosion reactions). Metals above hydrogen in the series displace hydrogen more easily than do those below it. As a general rule, when dissimilar metals are used in contact with each other and are exposed to an electrically-conducting solution, combinations of metals should be chosen that are as close as possible to each other in the series. Coupling two metals widely separated in the series will generally produce accelerated attack on the more active metal. Often, however, protective passive oxide films and other effects will tend to reduce galvanic corrosion. Insulating the metals from each other can prevent corrosion. The dual action of stress and a corrodent may result in stress corrosion cracking or corrosion fatigue.

Corrosion may be uniform or be intensely localized, characterized by pitting. The mechanisms can be direct oxidation, e.g. when a metal is heated in an oxidizing environment, or electrochemical. Galvanic corrosion may evolve sufficient hydrogen to cause a hazard, due to:

- Formation of a flammable atmosphere with air in equipment or piping.
- Build-up of internal pressure within a weakening container.
- Production of atomic hydrogen as a species; this may penetrate metal to produce blistering or embrittlement.

The consumption of oxygen due to atmospheric corrosion of sealed metal tanks may cause a hazard, due to oxygen-deficiency affecting persons on entry.

Stresses may develop resulting from the increased volume of corrosion products, e.g. rust formation involves a seven-fold increase in volume.

Many salts are corrosive to common materials of construction, as demonstrated in Tables 4.8 and 4.9. Corrosion may be promoted, or accelerated, by traces of contaminants.

Whereas corrosion of metals is due to chemical or substantial electrochemical attack, the deterioration of plastics and other non-metals which are susceptible to swelling, cracking, crazing, softening etc. is essentially physicochemical rather than electrochemical.

### *Corrosion prevention*

Corrosion prevention is achieved by correct choice of material of construction, by physical means (e.g. paints or metallic, porcelain, plastic or enamel linings or coatings) or by chemical means (e.g. alloying or coating). Some metals, e.g. aluminium, are rendered passive by the formation of an inert protective film. Alternatively a metal to be protected may be linked electrically to a more easily corroded metal, e.g. magnesium, to serve as a sacrificial anode.

Some corrosion-resistant materials for concentrated aqueous solutions and acids are given in Tables 4.10 and 4.11. The resistance of some common polymers to organic solvents is summarized in Table 4.12. The attack process is accelerated by an increase in temperature. The chemical resistance of a range of common plastics is summarized in Table 4.13.

**Table 4.8 Comparison of corrosion rates by solutions of salts**

| Salts<br>(type and examples)     | Corrosion rates for listed construction materials |              |              |                           |            |
|----------------------------------|---------------------------------------------------|--------------|--------------|---------------------------|------------|
|                                  | Carbon steel                                      | 304 SS       | 316 SS       | Alloy 400<br>(65 Ni-32Cu) | Nickel 200 |
| <b>Non-oxidizing non-halides</b> |                                                   |              |              |                           |            |
| Alkaline (pH >10)                |                                                   |              |              |                           |            |
| e.g. sodium carbonate            | L                                                 | L            | L            | L                         | L          |
| Neutral                          |                                                   |              |              |                           |            |
| e.g. sodium sulphate             | M                                                 | L-M; SCC     | L-M          | L                         | L          |
| sodium nitrate                   | L-M; SCC                                          | L; pits      | L, pits      | L                         | L          |
| Acid                             |                                                   |              |              |                           |            |
| e.g. nickel sulphate             | S                                                 | L-M          | L-M          | M                         | M; pits    |
| <b>Non-oxidizing halides</b>     |                                                   |              |              |                           |            |
| Neutral                          |                                                   |              |              |                           |            |
| e.g. sodium chloride             | M; pits                                           | M; SCC; pits | M; SCC; pits | M                         | M          |
| Acid                             |                                                   |              |              |                           |            |
| e.g. zinc chloride               | S                                                 | S; SCC; pits | S; SCC; pits | M                         | M          |
| ammonium chloride                | S                                                 | S; SCC; pits | M; SCC; pits | M                         | M-S        |
| <b>Oxidizing non-halides</b>     |                                                   |              |              |                           |            |
| Neutral                          |                                                   |              |              |                           |            |
| e.g. sodium chromate             | L <sup>(1)</sup>                                  | L            | L            | L                         | L          |
| sodium nitrite                   | L <sup>(1)</sup>                                  | L            | L            | L                         | L          |
| potassium permanganate           | M                                                 | M            | M            | M                         | M          |
| Acid                             |                                                   |              |              |                           |            |
| e.g. ferric sulphate             | S                                                 | L            | L            | S                         | —          |
| silver nitrate                   | S; SCC                                            | M            | M            | S                         | S          |
| <b>Oxidizing halides</b>         |                                                   |              |              |                           |            |
| Alkaline                         |                                                   |              |              |                           |            |
| e.g. sodium hypochlorite         | S                                                 | S; pits      | S; pits      | M-S; pits                 | M-S; pits  |
| Acid                             |                                                   |              |              |                           |            |
| e.g. ferric chloride             | S; SCC                                            | S; pits      | S; pits      | S                         | S          |
| cupric chloride                  | S                                                 | S; pits      | S; pits      | S                         | S          |
| mercuric chloride                | S                                                 | S; SCC; pits | S; SCC; pits | S; SCC                    | S          |

L Low: <5 mpy, for all concentrations and temperatures <boiling

M Moderate: <20 mpy, perhaps limited to lower concentrations and/or temperatures

S Severe: >50 mpy

SCC Induces stress corrosion cracking

(mpy = mils per year: 1 mil = 0.001 in = 25.4  $\mu$ m)

<sup>(1)</sup>Chemical acts as corrosion inhibitor if present in sufficient amounts, but may cause pitting if in lower amounts.

## Force and pressure

Pressure is defined as force per unit area. (It may be expressed in a variety of units; refer to Chapter 18.) So, pressure  $\times$  area = force.

As a result:

A relatively small pressure can result in a very large force if it is applied over a large area. Inadequately vented atmospheric storage tanks may therefore rupture if, for some reason, e.g. a high inflow, they are subjected to a relatively low internal pressure. Large side-on structures, windows, etc. are particularly prone to damage from an explosion even at a significant distance from the epicentre.

**Table 4.9 Selected inorganic salts highly corrosive to carbon steel (Corrosion rate >50 mpy)**

|                           |                           |
|---------------------------|---------------------------|
| Aluminium sulphate        | Magnesium fluorosilicate  |
| Ammonium bifluoride       | Mercuric chloride         |
| Ammonium bisulphite       | Nickel chloride           |
| Ammonium bromide          | Nickel sulphate           |
| Ammonium persulphate      | Potassium bisulphate      |
| Antimony trichloride      | Potassium bisulphite      |
| Beryllium chloride        | Potassium sulphite        |
| Cadmium chloride          | Silver nitrate            |
| Calcium hypochlorite      | Sodium aluminium sulphate |
| Copper nitrate            | Sodium bisulphate         |
| Copper sulphate           | Sodium hypochlorite       |
| Cupric chloride           | Sodium perchlorate        |
| Cuprous chloride          | Sodium thiocyanate        |
| Ferric chloride           | Stannic ammonium chloride |
| Ferric nitrate            | Stannic chloride          |
| Ferrous ammonium sulphate | Stannous chloride         |
| Ferrous chloride          | Uranyl nitrate            |
| Ferrous sulphate          | Zinc chloride             |
| Lead nitrate              | Zinc fluorosilicate       |
| Lithium chloride          |                           |

High-pressure equipment, the walls of gas cylinders, etc., are subjected to very high forces. Hence metallurgical integrity is vital.

Implosion of glass, plastic or inadequately designed metal equipment can occur under partial vacuum conditions.

### ***Stored pressure energy***

Any gas stored or transferred under pressure represents an energy source. If piping or equipment failure occurs, energy is given out as the gas rapidly expands down to virtually atmospheric pressure. Elastic strain energy in the walls is also given out, but, by comparison, this is relatively small.

For a perfect gas the energy content is:

$$W = \frac{P_o V \ln P_o}{P_a}$$

where  $W$  is the energy content (joules),  $V$  is the container volume ( $\text{m}^3$ ), and  $P_o$  and  $P_a$  are the internal and atmospheric pressure (Mpa), respectively. As a result:

Pressure rupture of even a small piece of equipment may result in a serious explosion generating missiles travelling at high velocity. This is an important consideration when using laboratory glassware or industrial glass equipment and pipework.

A pressure not registered on a gauge may be sufficient to result in an accident.

Pneumatic testing of equipment should only be used when hydraulic testing is impracticable; appropriate safeguards, e.g. pre-inspection, reduction of the internal gas space, pressure relief, and use of a blast pit or enclosure, are necessary.

High inventories of stored pressure energy constitute a major accident hazard.



**Table 4.10 Corrosion-resistant materials for concentrated aqueous solutions**

| Material                      | Acids     |                                        |                          |                                      |           |          |             |             |                | Alkalies                     | Salts             |       |                   | Organic solvents | Not recommended for |                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------|-----------|----------------------------------------|--------------------------|--------------------------------------|-----------|----------|-------------|-------------|----------------|------------------------------|-------------------|-------|-------------------|------------------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               | Oxidizing |                                        |                          | Reducing                             |           |          | Organic     |             |                |                              | Aqueous solutions |       |                   |                  |                     |                                                                                                                                                                                                                                                                                                                                                                                                                     |
|                               | Oleum     | 70–100% H <sub>2</sub> SO <sub>4</sub> | HNO <sub>3</sub> (conc.) | 0–70% H <sub>2</sub> SO <sub>4</sub> | 0–37% HCl | 0.80% HF | Acetic acid | Formic acid | NaOH (caustic) | NH <sub>4</sub> OH (ammonia) | NaCl              | NaOCl | FeCl <sub>3</sub> | Aliphatics       | Aromatics           |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Alloy C                       | L         | L                                      | L                        | R                                    | L         | L        | R           | R           | R              | R                            | R                 | R     | L                 | R                | R                   | Acid services >65 C, especially hydrochloric acid or acid solutions with high chloride contents<br>Hot oleum (>50 C), strong alkalis, fluoride solutions, sulphur trioxide<br>Strong alkalis, especially >54 C, distilled water >82 C, hydrofluoric acid, acid fluorides, hot concentrated phosphoric acid, lithium compounds >177 C, severe shock or impact applications<br>Strong oxidizers, very strong solvents |
| Tantalum                      | V         | R                                      | R                        | L                                    | R         | N        | R           | R           | N              | N                            | R                 | R     | R                 | R                | R                   |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Glass/silicates               | R         | R                                      | R                        | R                                    | R         | N        | R           | R           | L              | L                            | R                 | R     | R                 | R                | R                   |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Carbon, impreg. with furan    | N         | L                                      | L                        | –                                    | –         | L        | –           | –           | R              | R                            | R                 | R     | R                 | –                | –                   | Strong alkalis, very strong oxidizers<br><br>Molten alkali metals, elemental fluorine, strong fluorinating agents<br>Strongly oxidizing solutions, liquid bromine, pyridine<br>Strong alkalis or alkali salts, very strong oxidizers<br>Strong oxidizing conditions, very strong organic solvents                                                                                                                   |
| Carbon, impreg. with phenolic | N         | L                                      | L                        | R                                    | R         | L        | R           | R           | N              | R                            | R                 | R     | R                 | R                | R                   |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| FEP/TFE                       | R         | R                                      | R                        | R                                    | R         | R        | R           | R           | R              | R                            | R                 | R     | R                 | R                | R <sup>(1)</sup>    |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Furan resin                   | N         | N                                      | V                        | R                                    | L         | N        | L           | L           | R              | R                            | R                 | V     | R                 | R                | L <sup>(1)</sup>    |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Phenolic resin                | N         | L                                      | V                        | R                                    | R         | L        | L           | R           | N              | N                            | R                 | N     | L                 | R                | L <sup>(1)</sup>    |                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Epoxy resin <sup>(2)</sup>    | N         | N                                      | V                        | L                                    | R         | –        | L           | N           | R              | L                            | R                 | N     | R                 | L                | L <sup>(1)</sup>    |                                                                                                                                                                                                                                                                                                                                                                                                                     |

R Recommended for full range concentrations up to boiling or to temperature limit of (non-metallic) product form.

L Generally good service but limited in concentration and/or temperature.

V Very limited in concentration and/or temperature for service.

N Not recommended.

<sup>(1)</sup> See Table 4.12

<sup>(2)</sup> Epoxy hardener will strongly affect chemical resistance.

**Table 4.11 Construction materials for use with strong acids**

| <i>Acid</i>  | <i>Construction material</i>                   | <i>Important safety consideration</i>                                                                                                                                                                                                     |
|--------------|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acetic       | 316 L stainless steel                          | Excess acetic anhydride in glacial acetic acid can accelerate corrosion; chloride impurities (ppm levels) can cause pitting and stress-corrosion cracking                                                                                 |
|              | Copper/copper alloys<br>Aluminium alloys       | Not for highly oxidizing conditions<br>Sensitive to contaminants; requires very clean welding; attacked very rapidly in concentrations near 100% or with excess acetic anhydride                                                          |
| Formic       | 304 L stainless steel                          | For ambient temperature only                                                                                                                                                                                                              |
|              | Copper/copper alloys                           | Not for oxidizing conditions, including air                                                                                                                                                                                               |
| Hydrochloric | Rubber-lined steel (natural rubber)            | Low tolerance for organic solvent impurities; temperature limited according to hardness of rubber; steel fabrication must be properly done                                                                                                |
|              | Alloy C                                        | Not for hot concentrated HCl                                                                                                                                                                                                              |
|              | Alloy B                                        | Not for oxidizing conditions (test if reducing conditions are in doubt)                                                                                                                                                                   |
|              | Tantalum                                       | Not for fluoride impurities                                                                                                                                                                                                               |
|              | Impervious graphite<br>Reinforced plastic      | Fragile<br>HCl may attack or permeate laminate; temperature limited (<65.5 C); requires excellent engineering design and fabrication quality                                                                                              |
| Hydrofluoric | Alloy 400                                      | Not for oxidizing conditions (test if in doubt)                                                                                                                                                                                           |
|              | Copper                                         | Not for oxidizing conditions (test if in doubt); <65.5 C only.                                                                                                                                                                            |
|              | Cupro-nickel                                   | Not for oxidizing conditions (test if in doubt); concentration and temperature slightly limited                                                                                                                                           |
|              | Carbon steel                                   | Not below 60% concentration, depending on impurities                                                                                                                                                                                      |
|              | Impervious graphite<br>Polyvinylidene fluoride | Fragile; limit to below 60% concentration<br>–                                                                                                                                                                                            |
| Nitric       | 304 L stainless steel                          | Must use low-carbon (or stabilized grade) if welded; not for fuming acid concentrations above 65.5 C                                                                                                                                      |
|              | High-silicon iron                              | Casting only; limited shock resistance; only for concentrations above 45% if temperatures over 71 C                                                                                                                                       |
|              | Aluminium (e.g. 3003, 5052)                    | Mostly for over 95% concentration, not for below 85% concentration; requires very clean welding.                                                                                                                                          |
|              | Titanium                                       | May ignite in red-fuming nitric acid if water is below 1.5% and nitrogen dioxide is above 2.5%                                                                                                                                            |
| Oleum        | Carbon steel                                   | Not for 100–101% H <sub>2</sub> SO <sub>4</sub> concentration; limited in temperature                                                                                                                                                     |
|              | Glass-lined steel                              | Limited shock resistance                                                                                                                                                                                                                  |
| Phosphoric   | 316 L stainless steel                          | Must use low-carbon or stabilized grade if welded, up to 85% concentration and 93 C                                                                                                                                                       |
| Sulphuric    | Carbon steel                                   | Not for below 70% concentration; ambient temperatures only; flow velocities below 0.6 to 1.2 m/s                                                                                                                                          |
|              | Alloy 20 variations                            | Limited temperature at 65–75% concentration                                                                                                                                                                                               |
|              | High-silicon iron                              | Castings only; limited shock resistance                                                                                                                                                                                                   |
|              | Chemical lead                                  | Soft and suffers from erosion; creeps at room temperature; limit to below 90% concentration                                                                                                                                               |
|              | Glass                                          | Limited shock resistance                                                                                                                                                                                                                  |
|              | Alloy C                                        | Better for reducing acid strengths (<60% concentration)                                                                                                                                                                                   |
|              | Rubber-lined steel                             | For dilute not concentrated (oxidizing) strengths; temperature limited according to rubber hardness and acid concentration; steel fabrication must be properly done                                                                       |
|              | Brick linings with silicate mortar             | Absorption of the corrosive by the masonry (use membrane substrate); poor properties in tension or shear (use in compression); many brick linings ‘grow’ in service but if used in archlike contours, growth merely increases compression |

**Table 4.12 Solvent resistance of polymers**

| Solvent | Example | Thermosetting resins |  |  |  |  | Thermoplastics |  |  |  | Elastomers |  |  |  |
|---------|---------|----------------------|--|--|--|--|----------------|--|--|--|------------|--|--|--|
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |
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|         |         |                      |  |  |  |  |                |  |  |  |            |  |  |  |

E Recommended to maximum temperature of product form.

G Recommendation limited to somewhat lower temperature, or restricted in product from.

F Very limited recommendation; for ambient temperature only.

P Not recommended. Severe attack.

(Temperatures are approximate maxima.)

## Expansion and contraction of solids

Hazardous situations can develop with changes in volume with temperature. The effect of temperature on gases and liquids is mentioned on pages 45 and 65, respectively.

The thermal expansion and contraction of solids can also have safety implications. For a given material the amount of its linear expansion, or contraction, in one direction is directly related to temperature and its original size (i.e. length, diameter, circumference). Thus:

$$\text{change in length} = \alpha L \Delta t$$

where  $\alpha$  = thermal coefficient of linear expansion,

$\Delta t$  = change in temperature, and

$L$  = original linear measurement.

Table 4.14 lists the coefficients of expansion for selected materials of construction.

Thus, unacceptable stresses can arise in rigid construction materials in apparatus, equipment, piping, etc. if subjected to large temperature fluctuations. For example, conventional glass is prone to failure due to thermal shock.

Table 4.13 Chemical resistance of common plastics

| Chemical                   | Resins |     |    |     |              |    |     |
|----------------------------|--------|-----|----|-----|--------------|----|-----|
|                            | CPE    | LPE | PP | PMP | FEP/<br>ETFE | PC | PVC |
| Acetaldehyde               | GN     | GF  | GN | GN  | EE           | FN | GN  |
| Acetamide, sat.            | EE     | EE  | EE | EE  | EE           | NN | NN  |
| Acetic acid, 5%            | EE     | EE  | EE | EE  | EE           | EG | EE  |
| Acetic acid, 50%           | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Acetone                    | EE     | EE  | EE | EE  | EE           | NN | FN  |
| Adipic acid                | EG     | EE  | EE | EE  | EE           | EE | EG  |
| Alanine                    | EE     | EE  | EE | EE  | EE           | NN | NN  |
| Allyl alcohol              | EE     | EE  | EE | EG  | EE           | EG | GF  |
| Aluminium hydroxide        | EG     | EE  | EG | EG  | EE           | FN | EG  |
| Aluminium salts            | EE     | EE  | EE | EE  | EE           | EG | EE  |
| Amino acids                | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Ammonia                    | EE     | EE  | EE | EE  | EE           | NN | EG  |
| Ammonium acetate, sat.     | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Ammonium glycolate         | EG     | EE  | EG | EG  | EE           | GF | EE  |
| Ammonium hydroxide, 5%     | EE     | EE  | EE | EE  | EE           | FN | EE  |
| Ammonium hydroxide         | EG     | EE  | EG | EG  | EE           | NN | EG  |
| Ammonium oxalate           | EG     | EE  | EG | EG  | EE           | EE | EE  |
| Ammonium salts             | EE     | EE  | EE | EE  | EE           | EG | EG  |
| <i>n</i> -Amyl acetate     | GF     | EG  | GF | GF  | EE           | NN | FN  |
| Amyl chloride              | NN     | FN  | NN | NN  | EE           | NN | NN  |
| Aniline                    | EG     | EG  | GF | GF  | EE           | FN | NN  |
| Antimony salts             | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Arsenic salts              | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Barium salts               | EE     | EE  | EE | EE  | EE           | EE | EG  |
| Benzaldehyde               | EG     | EE  | EG | EG  | EE           | FN | NN  |
| Benzene                    | FN     | GG  | GF | GF  | EE           | NN | NN  |
| Benzoic acid, sat.         | EE     | EE  | EG | EG  | EE           | EG | EG  |
| Benzyl acetate             | EG     | EE  | EG | EG  | EE           | FN | FN  |
| Benzyl alcohol             | NN     | FN  | NN | NN  | EE           | GF | GF  |
| Bismuth salts              | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Boric acid                 | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Boron salts                | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Brine                      | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Bromine                    | NN     | FN  | NN | NN  | EE           | FN | GN  |
| Bromobenzene               | NN     | FN  | NN | NN  | EE           | NN | NN  |
| Bromoform                  | NN     | NN  | NN | NN  | EE           | NN | NN  |
| Butadiene                  | NN     | FN  | NN | NN  | EE           | NN | FN  |
| <i>n</i> -Butyl acetate    | GF     | EG  | GF | GF  | EE           | NN | NN  |
| <i>n</i> -Butyl alcohol    | EE     | EE  | EE | EG  | EE           | GF | GF  |
| sec-Butyl alcohol          | EG     | EE  | EG | EG  | EE           | GF | GG  |
| tert-Butyl alcohol         | EG     | EE  | EG | EG  | EE           | GF | EG  |
| Butyric acid               | NN     | FN  | NN | NN  | EE           | FN | GN  |
| Cadmium salts              | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Calcium hydroxide, conc.   | EE     | EE  | EE | EE  | EE           | NN | EE  |
| Calcium hypochlorite, sat. | EE     | EE  | EE | EG  | EE           | FN | GF  |
| Carbazole                  | EE     | EE  | EE | EE  | EE           | NN | NN  |
| Carbon bisulphide          | NN     | NN  | EG | FN  | EE           | NN | NN  |
| Castor oil                 | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Cedarwood oil              | NN     | FN  | NN | NN  | EE           | GF | FN  |
| Cellosolve acetate         | EG     | EE  | EG | EG  | EE           | FN | FN  |
| Caesium salts              | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Chlorine, 10% in air       | GN     | EF  | GN | GN  | EE           | EG | EE  |
| Chlorine, 10% (moist)      | GN     | GF  | GN | GN  | EE           | GF | EG  |
| Chloroacetic acid          | EE     | EE  | EG | EG  | EE           | FN | FN  |

Table 4.13 Cont'd

| Chemical                      | Resins |     |    |     |              |    |     |
|-------------------------------|--------|-----|----|-----|--------------|----|-----|
|                               | CPE    | LPE | PP | PMP | FEP/<br>ETFE | PC | PVC |
| <i>p</i> -Chloroacetophenone  | EE     | EE  | EE | EE  | EE           | NN | NN  |
| Chloroform                    | FN     | GF  | GF | FN  | EE           | NN | NN  |
| Chromic acid, 10%             | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Chromic acid, 50%             | EE     | EE  | EG | EG  | EE           | EG | EF  |
| Cinnamon oil                  | NN     | FN  | NN | NN  | EE           | GF | NN  |
| Citric acid, 10%              | EE     | EE  | EE | EE  | EE           | EG | GG  |
| Citric acid, crystals         | EE     | EE  | EE | EE  | EE           | EE | EG  |
| Coconut oil                   | EE     | EE  | EE | EG  | EE           | EE | GF  |
| Cresol                        | NN     | FN  | EG | NN  | EE           | NN | NN  |
| Cyclohexane                   | GF     | EG  | GF | NN  | EE           | EG | GF  |
| Decalin                       | GF     | EG  | GF | FN  | EE           | NN | EG  |
| <i>o</i> -Dichlorobenzene     | FN     | FF  | FN | FN  | EE           | NN | GN  |
| <i>p</i> -Dichlorobenzene     | FN     | GF  | EF | GF  | EE           | NN | NN  |
| Diethyl benzene               | NN     | FN  | NN | NN  | EE           | FN | NN  |
| Diethyl ether                 | NN     | FN  | NN | NN  | EE           | NN | FN  |
| Diethyl ketone                | GF     | GG  | GG | GF  | EE           | NN | NN  |
| Diethyl malonate              | EE     | EE  | EE | EG  | EE           | FN | GN  |
| Diethylene glycol             | EE     | EE  | EE | EE  | EE           | GF | FN  |
| Diethylene glycol ethyl ether | EE     | EE  | EE | EE  | EE           | FN | FN  |
| Dimethyl formamide            | EE     | EE  | EE | EE  | EE           | NN | FN  |
| Dimethylsulphoxide            | EE     | EE  | EE | EE  | EE           | NN | NN  |
| 1,4-Dioxane                   | GF     | GG  | GF | GF  | EE           | GF | FN  |
| Dipropylene glycol            | EE     | EE  | EE | EE  | EE           | GF | GF  |
| Ether                         | NN     | FN  | NN | NN  | EE           | NN | FN  |
| Ethyl acetate                 | EE     | EE  | EE | EG  | EE           | NN | FN  |
| Ethyl alcohol                 | EG     | EE  | EG | EG  | EE           | EG | EG  |
| Ethyl alcohol, 40%            | EG     | EE  | EG | EG  | EE           | EG | EE  |
| Ethyl benzene                 | FN     | GF  | FN | FN  | EE           | NN | NN  |
| Ethyl benzoate                | FF     | GG  | GF | GF  | EE           | NN | NN  |
| Ethyl butyrate                | GN     | GF  | GN | FN  | EE           | NN | NN  |
| Ethyl chloride, liquid        | FN     | FF  | FN | FN  | EE           | NN | NN  |
| Ethyl cyanoacetate            | EE     | EE  | EE | EE  | EE           | FN | FN  |
| Ethyl lactate                 | EE     | EE  | EE | EE  | EE           | FN | FN  |
| Ethylene chloride             | GN     | GF  | FN | NN  | EE           | NN | NN  |
| Ethylene glycol               | EE     | EE  | EE | EE  | EE           | GF | EE  |
| Ethylene glycol methyl ether  | EE     | EE  | EE | EE  | EE           | FN | FN  |
| Ethylene oxide                | FF     | GF  | FF | FN  | EE           | FN | FN  |
| Fluorides                     | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Fluorine                      | FN     | GN  | FN | FN  | EG           | GF | EG  |
| Formaldehyde, 10%             | EE     | EE  | EE | EG  | EE           | EG | GF  |
| Formaldehyde, 40%             | EG     | EE  | EG | EG  | EE           | EG | GF  |
| Formic acid, 3%               | EG     | EE  | EG | EG  | EE           | EG | GF  |
| Formic acid, 50%              | EG     | EE  | EG | EG  | EE           | EG | GF  |
| Formic acid, 98–100%          | EG     | EE  | EG | EF  | EE           | EF | FN  |
| Fuel oil                      | FN     | GF  | EG | GF  | EE           | EG | EE  |
| Gasoline                      | FN     | GG  | GF | GF  | EE           | FF | GN  |
| Glacial acetic acid           | EG     | EE  | EG | EG  | EE           | GF | EG  |
| Glycerine                     | EE     | EE  | EE | EE  | EE           | EE | EE  |
| <i>n</i> -Heptane             | FN     | GF  | FF | FF  | EE           | EG | FN  |
| Hexane                        | NN     | GF  | EF | FN  | EE           | FN | GN  |
| Hydrochloric acid, 1–5%       | EE     | EE  | EE | EG  | EE           | EE | EE  |
| Hydrochloric acid, 20%        | EE     | EE  | EE | EG  | EE           | EG | EG  |
| Hydrochloric acid, 35%        | EE     | EE  | EG | EG  | EE           | GF | GF  |
| Hydrofluoric acid, 4%         | EG     | EE  | EG | EG  | EE           | GF | GF  |

Table 4.13 Cont'd

| Chemical                   | Resins |     |    |     |              |    |     |
|----------------------------|--------|-----|----|-----|--------------|----|-----|
|                            | CPE    | LPE | PP | PMP | FEP/<br>ETFE | PC | PVC |
| Hydrofluoric acid, 48%     | EE     | EE  | EE | EE  | EE           | NN | GF  |
| Hydrogen                   | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Hydrogen peroxide, 3%      | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Hydrogen peroxide, 30%     | EG     | EE  | EG | EG  | EE           | EE | EE  |
| Hydrogen peroxide, 90%     | EG     | EE  | EG | EG  | EE           | EE | EG  |
| Isobutyl alcohol           | EE     | EE  | EE | EG  | EE           | EG | EG  |
| Isopropyl acetate          | GF     | EG  | GF | GF  | EE           | NN | NN  |
| Isopropyl alcohol          | EE     | EE  | EE | EE  | EE           | EE | EG  |
| Isopropyl benzene          | FN     | GF  | FN | NN  | EE           | NN | NN  |
| Kerosene                   | FN     | GG  | GF | GF  | EE           | GF | EE  |
| Lactic acid, 3%            | EG     | EE  | EG | EG  | EE           | EG | GF  |
| Lactic acid, 85%           | EE     | EE  | EG | EG  | EE           | EG | GF  |
| Lead salts                 | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Lithium salts              | EE     | EE  | EE | EE  | EE           | GF | EE  |
| Magnesium salts            | EE     | EE  | EE | EE  | EE           | EG | EE  |
| Mercuric salts             | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Mercurous salts            | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Methoxyethyl oleate        | EG     | EE  | EG | EG  | EE           | FN | NN  |
| Methyl alcohol             | EE     | EE  | EE | EE  | EE           | FN | EF  |
| Methyl ethyl ketone        | EG     | EE  | EG | EF  | EE           | NN | NN  |
| Methyl isobutyl ketone     | GF     | EG  | GF | FF  | EE           | NN | NN  |
| Methyl propyl ketone       | GF     | EG  | GF | FF  | EE           | NN | NN  |
| Methylene chloride         | FN     | GF  | FN | FN  | EE           | NN | NN  |
| Mineral oil                | GN     | EE  | EE | EG  | EE           | EG | EG  |
| Nickel salts               | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Nitric acid, 1–10%         | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Nitric acid, 50%           | EG     | GN  | GN | GN  | EE           | GF | GF  |
| Nitric acid, 70%           | EN     | GN  | GN | GN  | EE           | FN | FN  |
| Nitrobenzene               | NN     | FN  | NN | NN  | EE           | NN | NN  |
| <i>n</i> -Octane           | EE     | EE  | EE | EE  | EE           | GF | FN  |
| Orange oil                 | FN     | GF  | GF | FF  | EE           | FF | FN  |
| Ozone                      | EG     | EE  | EG | EE  | EE           | EG | EG  |
| Perchloric acid            | GN     | GN  | GN | GN  | GF           | NN | GN  |
| Perchloroethylene          | NN     | NN  | NN | NN  | EE           | NN | NN  |
| Phenol, crystals           | GN     | GF  | GN | FG  | EE           | EN | FN  |
| Phosphoric acid, 1–5%      | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Phosphoric acid, 85%       | EE     | EE  | EG | EG  | EE           | EG | EG  |
| Phosphorus salts           | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Pine oil                   | GN     | EG  | EG | GF  | EE           | GF | FN  |
| Potassium hydroxide, 1%    | EE     | EE  | EE | EE  | EE           | FN | EE  |
| Potassium hydroxide, conc. | EE     | EE  | EE | EE  | EE           | NN | EG  |
| Propane gas                | NN     | FN  | NN | NN  | EE           | FN | EG  |
| Propylene glycol           | EE     | EE  | EE | EE  | EE           | GF | FN  |
| Propylene oxide            | EG     | EE  | EG | EG  | EE           | GF | FN  |
| Resorcinol, sat.           | EE     | EE  | EE | EE  | EE           | GF | FN  |
| Resorcinol, 5%             | EE     | EE  | EE | EE  | EE           | GF | GN  |
| Salicylaldehyde            | EG     | EE  | EG | EG  | EE           | GF | FN  |
| Salicylic acid, powder     | EE     | EE  | EE | EG  | EE           | EG | GF  |
| Salicylic acid, sat.       | EE     | EE  | EE | EE  | EE           | EG | GF  |
| Salt solutions             | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Silver acetate             | EE     | EE  | EE | EE  | EE           | EG | GG  |
| Silver salts               | EG     | EE  | EG | EE  | EE           | EE | EG  |
| Sodium acetate, sat.       | EE     | EE  | EE | EE  | EE           | EG | GF  |
| Sodium benzoate, 1%        | EE     | EE  | EE | EE  | EE           | EE | EE  |

Table 4.13 Cont'd

| Chemical                      | Resins |     |    |     |              |    |     |
|-------------------------------|--------|-----|----|-----|--------------|----|-----|
|                               | CPE    | LPE | PP | PMP | FEP/<br>ETFE | PC | PVC |
| Sodium hydroxide, 1%          | EE     | EE  | EE | EE  | EE           | FN | EE  |
| Sodium hydroxide, 50% to sat. | EE     | EE  | EE | EE  | EE           | NN | EG  |
| Sodium hypochlorite, 15%      | EE     | EE  | EE | EE  | EE           | GF | EE  |
| Stearic acid, crystals        | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Sulphuric acid, 1–6%          | EE     | EE  | EE | EE  | EE           | EE | EG  |
| Sulphuric acid, 20%           | EE     | EE  | EG | EG  | EE           | EG | EG  |
| Sulphuric acid, 60%           | EG     | EE  | EG | EG  | EE           | GF | EG  |
| Sulphuric acid, 98%           | EG     | EE  | EE | EE  | EE           | NN | NN  |
| Sulphur dioxide, liq., 46 psi | NN     | FN  | NN | NN  | EE           | GN | FN  |
| Sulphur dioxide, wet or dry   | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Sulphur salts                 | FN     | GF  | FN | FN  | EE           | FN | NN  |
| Tartaric acid                 | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Tetrachloromethane            | FN     | GF  | GF | NN  | EE           | NN | GF  |
| Tetrahydrofuran               | FN     | GF  | GF | FF  | EE           | NN | NN  |
| Thionyl chloride              | NN     | NN  | NN | NN  | EE           | NN | NN  |
| Titanium salts                | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Toluene                       | FN     | GG  | GF | FF  | EE           | FN | FN  |
| Tributyl citrate              | GF     | EG  | GF | GF  | EE           | NN | FN  |
| Trichloroethane               | NN     | FN  | NN | NN  | EE           | NN | NN  |
| Trichloroethylene             | NN     | FN  | NN | NN  | EE           | NN | NN  |
| Triethylene glycol            | EE     | EE  | EE | EE  | EE           | EG | GF  |
| Tripropylene glycol           | EE     | EE  | EE | EE  | EE           | EG | GF  |
| Turkey red oil                | EE     | EE  | EE | EE  | EE           | EG | EG  |
| Turpentine                    | FN     | GG  | GF | FF  | EE           | FN | GF  |
| Undecyl alcohol               | EF     | EG  | EG | EG  | EE           | GF | EF  |
| Urea                          | EE     | EE  | EE | EG  | EE           | NN | GN  |
| Vinylidene chloride           | NN     | FN  | NN | NN  | EE           | NN | NN  |
| Xylene                        | GN     | GF  | FN | FN  | EE           | NN | NN  |
| Zinc salts                    | EE     | EE  | EE | EE  | EE           | EE | EE  |
| Zinc stearate                 | EE     | EE  | EE | EE  | EE           | EE | EG  |

E 30 days of constant exposure cause no damage. Plastic may even tolerate exposure for years.

G Little or no damage after 30 days of constant exposure to the reagent.

F Some signs of attack after 7 days of constant exposure to the reagent.

N Not recommended; noticeable signs of attack occur within minutes to hours after exposure. (However, actual failure might take years.)

First letter: at room temperature.

Second letter: at 52 C.

#### Resins

CPE Conventional (low-density) polyethylene.

LPE Linear (high-density) polyethylene.

PP Polypropylene.

PMP Polymethylpentene.

FEP Teflon FEP (fluorinated ethylene propylene). Teflon is a Du Pont registered trademark.

ETFE Tefzel ethylene-tetrafluoroethylene copolymer. (For chemical resistance, see FEP ratings.) Tefzel is a Du Pont registered trademark.

PC Polycarbonate.

PVC Rigid polyvinyl chloride.

**Table 4.14 Thermal coefficients of linear expansion**

| <i>Material</i> | <i>Coefficient of expansion per °C</i> |
|-----------------|----------------------------------------|
| Aluminium       | 0.000025                               |
| Brass           | 0.000018                               |
| Bronze          | 0.000018                               |
| Copper          | 0.000017                               |
| Glass (Pyrex)   | 0.000003                               |
| Iron (cast)     | 0.000011                               |
| Lead            | 0.000029                               |
| Platinum        | 0.000009                               |
| Silver          | 0.000021                               |
| Steel (mild)    | 0.000012                               |
| Tin             | 0.000025                               |
| Zinc            | 0.000029                               |

**Table 4.15 Pressure increase of common liquids due to thermal expansion on 16.6 °C temperature rise**

| <i>Liquid</i>             | <i>P (psia)</i> |
|---------------------------|-----------------|
| Acetic acid               | 3200            |
| Acetone                   | 3260            |
| Aniline                   | 5190            |
| Benzene                   | 3860            |
| <i>n</i> -Butyl alcohol   | 2590            |
| Carbon tetrachloride      | 3310            |
| Methyl alcohol            | 3900            |
| Petroleum (s.g. = 0.8467) | 2340            |
| Toluene                   | 3340            |
| Water                     | 1100            |

Liquids can also exert pressure due to thermal expansion. Table 4.15 provides an indication of pressure increases due to temperature increases for selected common liquids in full containers or pipes. Serious accidents can arise unless the design of rigid plant items such as pipework takes into account the changes in volume of liquids with temperature fluctuation by the following or combinations thereof:

- Expansion bellows.
- Expansion joints.
- Expansion loops or offset legs.
- Positioning of equipment so as to exploit the inherent flexibility.
- Supports, guides, anchors, piles.
- Decrease in pipe wall thickness.

Consideration should be given to the effects of thermal expansion of liquids and pressure-relief valves installed unless:

- pipelines cannot become blocked or heated;
- liquid temperature is controlled;
- line is normally in service and can be vented and drained;
- one end of valve is fitted with check valve.



If pressure relief is important methods include:

- installation of pressure-relief valve;
- bypass;
- check valves;
- ensuring liquid is drained before blockage can occur.

# Toxic chemicals

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## Introduction

Chemicals may be encountered as reactants, solvents, catalysts, inhibitors, as starting materials, finished products, by-products, contaminants, or off-specification products. They may vary from pure, single substances to complex proprietary formulations.

Exposures to chemicals may involve solids, liquids, or airborne matter as mists, aerosols, dusts, fumes (i.e.  $\mu$ m-sized particulates), vapours or gases in any combination. Many situations, e.g. exposure to welding fumes or to combustion products from fossil fuels, include mixtures both of chemicals and of physical forms. Quantification of exposure is then difficult.

An exposure to a specific chemical in relatively low concentrations over a period may result in chronic effects. At higher concentrations, the effects may be acute. Some chemicals produce local damage at their point of contact with, or entry into, the body; others produce systemic effects, i.e. they are transported within the body to various organs before exerting an adverse effect.

For a classification of airborne contaminants, refer to Table 5.1

## Hazard recognition

The toxicity of a substance is its capacity to cause injury once inside the body. The main modes of entry into the body by chemicals in industry are inhalation, ingestion and absorption through the skin. Gases, vapours, mists, dusts, fumes and aerosols can be inhaled and they can also affect the skin, eyes and mucous membranes. Ingestion is rare although possible as a result of poor personal hygiene, subconscious hand-to-mouth contact, or accidents. The skin can be affected directly by contact with the chemicals, even when intact, but its permeability to certain substances also offers a route into the body. Chemicals accorded a 'skin' notation in the list of Occupational Exposure Limits (see Table 5.12) are listed in Table 5.2. Exposure may also arise via skin lesions.

## Types of toxic chemicals

### *Irritant chemicals*

Primary irritants cause inflammation. Inflammation is one of the body's defence mechanisms. It is the reaction of a tissue to harm which is insufficient to kill the tissue and is typified by

**Table 5.1 Classification of airborne contaminants**

| <i>Classification</i>                                                                                                                                                                                     | <i>Sub-groups</i>                                                                                                                  | <i>Examples</i>                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Irritants</b><br>Have a corrosive or a vesicant (blistering) effect on moist or mucous surfaces.<br>Concentration may be more important than duration of exposure.<br>Animals and man react similarly. |                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                              |
| (a) Primary                                                                                                                                                                                               | Upper respiratory                                                                                                                  | <i>Vapour, gases, mists</i><br>Acrolein; sulphur dioxide, hydrogen chloride, chromic acid; formaldehyde.                                                                                                                                                                                                                                                                                     |
|                                                                                                                                                                                                           | Upper and lower respiratory                                                                                                        | Fluorine; chlorine; bromine; ozone; cyanogen chloride.                                                                                                                                                                                                                                                                                                                                       |
|                                                                                                                                                                                                           | Lower respiratory                                                                                                                  | Phosgene; nitrogen dioxide; arsenic trichloride.                                                                                                                                                                                                                                                                                                                                             |
|                                                                                                                                                                                                           | Skin                                                                                                                               | Inorganic acids (chromic, nitric); organic acids (acetic, butyric); inorganic alkalis (sodium hydroxide, sodium carbonate); organic bases (amines); organic solvents.                                                                                                                                                                                                                        |
| (b) Secondary or allergens                                                                                                                                                                                |                                                                                                                                    | <i>Dusts</i><br>Detergents; salts (nickel sulphate, zinc chloride); acids, alkalis, chromates.                                                                                                                                                                                                                                                                                               |
|                                                                                                                                                                                                           | Skin sensitizers                                                                                                                   | Epoxy-resins; picryl chloride; or chlor-2-4-dinitrobenzene; <i>p</i> -phenyl diamine.                                                                                                                                                                                                                                                                                                        |
|                                                                                                                                                                                                           | Respiratory sensitizers                                                                                                            | Isocyanates; proteolytic enzymes; <i>p</i> -phenylene diamine; complex salts of platinum; cyanuric chloride.                                                                                                                                                                                                                                                                                 |
| <b>Asphyxiants</b><br>Exert an effect by interference with oxidation of tissue. Animals and man react similarly.                                                                                          |                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                              |
|                                                                                                                                                                                                           | Simple anoxia caused by oxygen deficiency in inhaled air.                                                                          | Carbon dioxide; methane; hydrogen; nitrogen; helium.                                                                                                                                                                                                                                                                                                                                         |
|                                                                                                                                                                                                           | Toxic anoxia caused by damage to the body's oxygen transport or utilization by adverse reaction of biologically active substances. | Carbon monoxide; cyanogen, hydrogen cyanide; nitrites; arsine; aniline, dimethyl aniline, toluidine; nitrobenzene; hydrogen sulphide (causes respiratory paralysis by impairment of oxygen utilization in the central nervous system).                                                                                                                                                       |
| <b>Anaesthetics and narcotics</b><br>Exert principal effects as simple anaesthesia, by a depressant action on the central nervous system.                                                                 |                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                              |
|                                                                                                                                                                                                           |                                                                                                                                    | <div>           Acetylene<br/>           Olefins<br/>           Ether<br/>           Paraffins<br/>           Aliphatic ketones<br/>           Aliphatic alcohols<br/>           Esters         </div> <div style="display: inline-block; vertical-align: middle; text-align: center;">           ↓<br/>           Decreasing anaesthetic action compared with other effects.         </div> |
| <b>Systemic poisons</b><br>Substances which cause injury at other than the site of contact.                                                                                                               |                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                              |
|                                                                                                                                                                                                           | Visceral organs in general<br>Haematopoietic (i.e. blood-forming system)<br>Nervous system                                         | Many halogenated hydrocarbons and metals.<br>Benzene; phenols.<br><br>Carbon disulphide; methanol; phenol; <i>n</i> -hexane; methyl <i>n</i> -butyl ketone; organophosphorus compounds; tetra-alkyl lead compounds.                                                                                                                                                                          |

Table 5.1 Cont'd

| <i>Classification</i>        | <i>Sub-groups</i>     | <i>Examples</i>                                                                                                                                                            |
|------------------------------|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              |                       | <i>Toxic inorganic substances</i> e.g.<br>Lead, manganese, cadmium, antimony,<br>beryllium, mercury; arsenic;<br>phosphorus; selenium and sulphur<br>compounds, fluorides. |
| <b>Respiratory fibrogens</b> |                       | <i>Fibrogenic dusts</i> e.g.<br>Free crystalline silica, (quartz, tridymite,<br>cristobalite), asbestos (chrysotile,<br>amosite, crocidolite etc.), talc.                  |
| <b>Carcinogens</b>           |                       |                                                                                                                                                                            |
| Cancer-producing agents      | Skin                  | Coal tar pitch dust; crude anthracene<br>dust; mineral oil mist; arsenic.                                                                                                  |
|                              | Respiratory           | Asbestos; polycyclic aromatic<br>hydrocarbons; nickel ore; arsenic;<br>bis-(chloromethyl) ether; mustard gas.                                                              |
|                              | Bladder/urinary tract | $\beta$ -naphthylamine; benzidine;<br>4-aminodiphenylamine.                                                                                                                |
|                              | Liver                 | Vinyl chloride monomer.                                                                                                                                                    |
|                              | Nasal                 | Mustard gas; nickel ore.                                                                                                                                                   |
|                              | Bone marrow           | Benzene.                                                                                                                                                                   |
| <b>Inerts</b>                |                       | <i>Gases</i><br>Simple asphyxiants<br>Argon; methane; hydrogen; nitrogen;<br>helium.<br><i>Particulates</i> e.g. cement, calcium<br>carbonate.                             |

constriction of the small vessels in the affected area, dilation of the blood vessels, increased permeability of the vessel walls, and migration of the white blood and other defensive cells to the invading harmful chemical. The aim is to concentrate water and protein in the affected area to 'dilute' the effect and wash away the chemical. Production of new cells is speeded up and contaminated surface cells are shed.

The respiratory system is the main target organ for vapour, gas or mist. Readily-soluble chemicals, e.g. chlorine or phosgene, attack the upper respiratory tract; less soluble gases, e.g. oxides of nitrogen, penetrate more deeply into the conducting airways and, in some cases, may cause pulmonary oedema, often after a time delay.

For example, sulphur dioxide is highly water soluble and tends to be absorbed in the airways above the larynx. Responses at various concentrations are summarized in Table 5.3. However, in the presence of particulate catalysts and sunlight, conversion to sulphur trioxide occurs and the irritant response is much more severe.

Other parts of the body are also vulnerable: the skin and eyes from direct contact/rubbing or from exposure to airborne material including splashes; the mouth and pharynx by ingestion of solid or liquid chemicals.

One effect of direct contact of liquid or solid, and less often vapour, with the skin is a contact irritant dermatitis. Some dusts can also act as primary irritants. Even chemically-inert dusts, e.g. from glass fibres, can induce a dermatitis due to abrasion; this is made worse if a reactive chemical, e.g. a synthetic resin binder, is also involved. Examples of primary irritants include acids; alkalis; defatting compounds, e.g. organic solvents, surfactants; dehydrating agents; oxidizing agents and reducing agents.

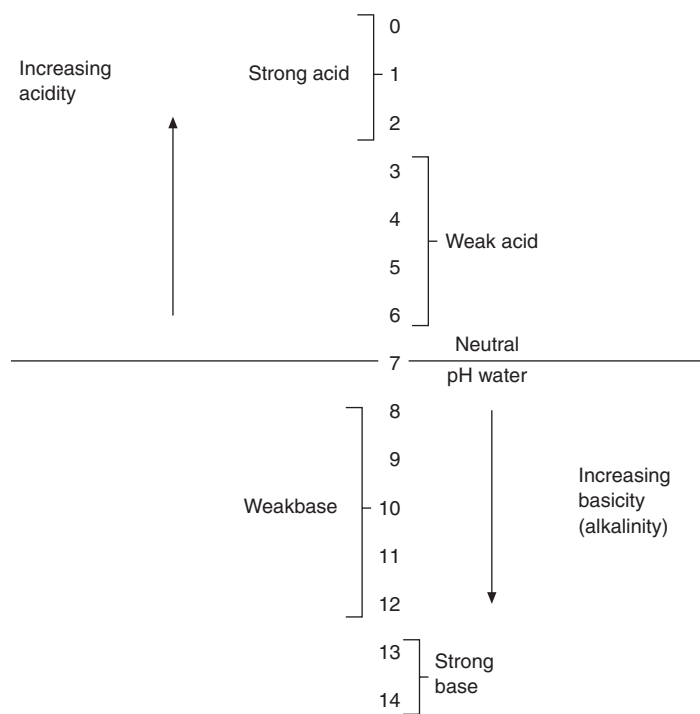
**Table 5.2 Materials with an 'Sk' notation in list of Occupational Exposure Limits**

|                                                |                                                |
|------------------------------------------------|------------------------------------------------|
| Acrylamide                                     | Hexan-2-one                                    |
| Acrylonitrile                                  | Hydrazine                                      |
| Aldrin                                         | Hydrogen cyanide                               |
| Allyl alcohol                                  | 2-Hydroxypropylacrylate                        |
| Aniline                                        | 2,2-Iminodi(ethylamine)                        |
| Azinphos-methyl                                | Iodomethane                                    |
| Aziridine                                      | Malathion                                      |
| Butan-1-ol                                     | Mercury alkyls                                 |
| 2-Butoxyethanol                                | Methacrylonitrile                              |
| n-Butylamine                                   | Methanol                                       |
| $\gamma$ -BHC (Lindane)                        | 2-Methoxyethanol                               |
| Bromoform                                      | 2-Methoxyethyl acetate                         |
| Bromomethane                                   | (2-Methoxymethylethoxy) propanol               |
| Butan-2-one                                    | Methoxypropanol                                |
| 2-sec-Butylphenol                              | 2-Methyl-4,6-dinitrophenol                     |
| Carbon disulphide                              | 5-Methylhexan-2-one                            |
| Carbon tetrachloride                           | 4-Methylpentan-2-ol                            |
| Chlorinated biphenyls                          | 4-Methylpentan-2-one                           |
| 2-Chlorobuta-1,3-diene                         | 1-Methyl-2-pyrrolidone                         |
| 1-Chloro-2,3-epoxy propane                     | N-Methyl-N-,2,4,6-tetranitroaniline            |
| 2-Chloroethanol                                | N-Methylaniline                                |
| Chloroform                                     | Mevinphos                                      |
| 1-Chloro-4-nitrobenzene                        | Monochloroacetic acid                          |
| Chlorpyrifos                                   | Morpholine                                     |
| Cresols, all isomers                           | Nicotine                                       |
| Cumene                                         | 4-Nitroaniline                                 |
| Cyanides                                       | Nitrobenzene                                   |
| Cyclohexylamine                                | Nitrotoluene                                   |
| Diazinon                                       | Octachloronaphthalene                          |
| 1,2-Dibromoethane                              | Parathion                                      |
| 2,2'-Dichloro-4,4'-methylene dianiline (MDOCA) | Parathion-methyl                               |
| 1,3-Dichloropropene                            | Pentachlorophenol                              |
| Dichlorvos                                     | Phenol                                         |
| Dieldrin                                       | Phorate                                        |
| 2-Diethylaminoethanol                          | Piperidine                                     |
| Diethyl sulphate                               | Polychlorinated biphenyls (PCB)                |
| Di-isopropylamine                              | Propan-1-ol                                    |
| N,N-Dimethylacetamide                          | Propylene dinitrate                            |
| N,N-Dimethylaniline                            | Prop-2-yn-1-ol                                 |
| Dimethyl formamide                             | Sodium fluoroacetate                           |
| Dimethyl sulphate                              | Sulfotep                                       |
| Dinitrobenzene                                 | Tetrabromoethane                               |
| 2,4-Dinitrotoluene                             | Tetraethylpyrophosphate                        |
| 1,4-Dioxane                                    | Tetrahydrofuran                                |
| Dioxathion                                     | Tetramethyl succinonitrile                     |
| Endosulfan                                     | Thallium, soluble compounds                    |
| Endrin                                         | Tin compounds, organic                         |
| 2-Ethoxyethanol                                | Toluene                                        |
| 2-Ethoxyethyl acetate                          | o-Toluidine                                    |
| Ethylene dinitrate                             | Tricarbonyl (eta-cyclopentadienyl) manganese   |
| 4-Ethylmorpholine                              | Tricarbonyl (methylcyclopentadienyl) manganese |
| 2-Furaldehyde (furfural)                       | Trichlorobenzene                               |
| Furfuryl alcohol                               | 1,1,2-Trichloroethane                          |
| Glycerol trinitrate                            | Trichloroethylene                              |
| Heptan-3-one                                   | 2,4,6-Trinitrotoluene                          |
| Heptan-2-one                                   | Xylene                                         |
| Hexahydro-1,3,5-trinitro-1,3,5-triazine        | Xylidine                                       |

**Table 5.3 Typical effects of sulphur dioxide concentrations in air**

| <i>Concentration<br/>(ppm)</i> | <i>Response</i>                                                   |
|--------------------------------|-------------------------------------------------------------------|
| 0.5–0.8                        | Minimum odour threshold                                           |
| 3                              | Sulphur-like odour detectable                                     |
| 6–12                           | Immediate irritation to nose and throat                           |
| 20                             | Reversible damage to respiratory system                           |
| >20                            | Eye irritation                                                    |
|                                | Tendency to pulmonary oedema and eventually respiratory paralysis |
| 10 000                         | Irritation to moist skin within a few minutes                     |

In extreme cases irritant chemicals can have a corrosive action. Corrosive substances can also attack living tissue (e.g. to cause skin ulceration and, in severe cases, chemical burns with degradation of biochemicals and charring), kill cells and possibly predispose to secondary bacterial invasion. Thus whilst acute irritation is a local and reversible response, corrosion is irreversible cell destruction at the site of the contact. The outcome is influenced by the nature of the compound, the concentration, duration of exposure, the pH (see Figure 5.1) and also, to some extent, by individual susceptibility etc. Thus dilute mineral acids may be irritant whereas at higher concentrations they may cause corrosion.

**Figure 5.1** *The pH scale*

A summary of the more common corrosive chemicals is given in Table 5.4. Note that this includes many primary irritants, such as:

Chemicals which give strong acid reactions, often on interaction with water, e.g. mineral acids. Some organic acids can also be corrosive. Phenolics can result in local anaesthesia so that the pain will be absent for a time, i.e. contact may go unheeded.

Halogen compounds.

Acid anhydrides/halides which react with water to form their parent acids.

Common bases, which render aqueous solutions alkaline.

Certain oxidizing/reducing compounds and salts which, in the form of solid (bulk or dust) or as solution, can produce irritation by thermal burns.

Strong acids and alkalis produce effects within moments: e.g. sulphuric and nitric acids quickly become hydrated by the water content of the skin/mucous membranes and combine with skin protein to form albuminates, sometimes with charring. Some substances, e.g. certain organotin or hydrofluoric acid, produce a more delayed reaction. Thus on the skin hydrofluoric acid produces an effect which varies, depending on concentration and duration of exposure, from mild erythema to severe burns and intense pain, sometimes delayed by several hours after the initial exposure. A tough white lump forms over the area of skin damage under which progressive destruction of cell tissue continues. Burns under the finger nails are notable in this respect because of the difficulties of treatment. Similarly, inhalation of the vapour can cause corrosion of the respiratory system and pulmonary oedema. If hydrofluoric acid is swallowed, burns to the mouth and pharynx can occur with vomiting and ultimate collapse.

### ***Sensitizers***

Generally sensitizers may not on first contact result in any ill effects, although cellular changes can be induced and the body's immune system affected. (Some chemicals may act as primary irritants as well as sensitizers.) Subsequent exposures to the same, or related, chemicals may bring about violent allergic responses: the person has become sensitized. Generally there is no mathematical relationship between the degree of exposure and the extent of the response. Sensitization to a compound is usually highly specific and normally occurs within about 10 days, although there have been cases of workers using a chemical for years without untoward effects before developing an allergic dermatitis. Sensitization is usually for life. Depending upon the toxic mechanism, atopics may be most vulnerable.

Thus with industrial skin sensitizers, e.g. chromates or amine curing agents, no effect is usually observed on first exposure; subsequent exposure results in inflammation of the skin, not restricted to the areas of contact. Refer to Table 5.5.

Respiratory sensitizers, e.g. isocyanates or formaldehyde, result, in mild cases, in a sense of tightness of the chest and occasionally a troublesome cough. Severe cases involve bronchial asthma. Refer to Table 5.6. With such sensitizers, complete cessation of contact is often followed by rapid recovery but no further exposure is generally permitted.

### ***Asphyxiants***

Asphyxiants interfere with the body's oxygen uptake mechanisms. Air normally contains 21% oxygen. Oxygen deficiency in inhaled air, e.g. due to the presence of nitrogen, argon, or carbon dioxide in a confined space, depending on the concentration and duration, may affect the body and ultimately cause death from simple anoxia (Table 5.7).

Table 5.4 Common corrosive chemicals

|                                                                |                                                                               |                                                        |
|----------------------------------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------|
| <b>Acids and anhydrides</b>                                    | Acetic acid                                                                   | Nitrohydrochloric acid                                 |
|                                                                | Acetic anhydride                                                              | Perchloric acid                                        |
|                                                                | Acid mixtures                                                                 | Phenosulphonic acid                                    |
|                                                                | Battery fluids                                                                | Phosphorus pentoxide                                   |
|                                                                | Chloroacetic acid                                                             | Propionic acid                                         |
|                                                                | Chlorosulphonic acid                                                          | Selenic acid                                           |
|                                                                | Chromic acid                                                                  | Spent acids                                            |
|                                                                | Dichloroacetic acid                                                           | Sulphamic acid                                         |
|                                                                | Fluoroboric acid                                                              | Sulphuric acid and oleum<br>(fuming sulphuric acid)    |
|                                                                | Fluorosilicic acid                                                            | Sulphurous acid                                        |
|                                                                | Hydrobromic, hydrochloric, hydrofluoric<br>and hydroiodic acids               | Thioglycolic acid                                      |
|                                                                | Methacrylic acid                                                              | Trichloroacetic acid                                   |
|                                                                | Nitric acid                                                                   |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
| <b>Alkalis</b>                                                 | Ammonium hydroxide                                                            |                                                        |
|                                                                | Potassium hydroxide (caustic potash)                                          |                                                        |
|                                                                | Quaternary ammonium hydroxides                                                |                                                        |
|                                                                | Sodium hydroxide (caustic soda)                                               |                                                        |
| <b>Halogens and halogen salts</b>                              | Aluminium bromide and chloride                                                | Phosphorus sulphochloride<br>(thiophosphoryl chloride) |
|                                                                | Ammonium bifluoride and<br>other bifluorides                                  | Phosphorus trichloride and pentachloride               |
|                                                                | Antimony trichloride, pentachloride<br>and pentafluoride                      | Potassium fluoride and bifluoride                      |
|                                                                | Beryllium chloride                                                            | Potassium hypochlorite                                 |
|                                                                | Boron trichloride                                                             | Pyrosulphuryl chloride                                 |
|                                                                | Bromine                                                                       | Sodium chloride                                        |
|                                                                | Chlorine                                                                      | Sodium fluoride                                        |
|                                                                | Calcium fluoride                                                              | Sodium hypochlorite                                    |
|                                                                | Chromic fluoride                                                              | Stannic chloride                                       |
|                                                                | Chromous fluoride                                                             | Sulphur chloride                                       |
|                                                                | Fluorine                                                                      | Sulphuryl chloride                                     |
|                                                                | Iodine                                                                        | Thionyl chloride                                       |
|                                                                | Iron chlorides (ferric chloride,<br>ferrous chloride)                         | Titanium tetrachloride                                 |
|                                                                | Lithium chloride                                                              | Vanadium dichloride                                    |
|                                                                | Phosphorus oxybromide and<br>oxychloride (phosphoryl bromide<br>and chloride) | Zinc chloride                                          |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
| <b>Interhalogen compounds</b>                                  | Bromine trifluoride and pentafluoride                                         |                                                        |
|                                                                | Chlorine trifluoride                                                          |                                                        |
|                                                                | Iodine monochloride                                                           |                                                        |
| <b>Organic halides, organic acid halides, esters and salts</b> | Acetyl bromide                                                                | <i>p</i> -Chlorobenzyl chloride                        |
|                                                                | Acrylonitrile monomer                                                         | Chloropropionyl chloride                               |
|                                                                | Allyl chloride                                                                | Dibromoethane (ethylene bromide)                       |
|                                                                | Allyl chloroformate                                                           | 1,2-Dichloroethane (ethylene chloride)                 |
|                                                                | Allyl iodide                                                                  | Diisooctyl acid phosphate                              |
|                                                                | Ammonium thiocyanate                                                          | Ethyl chloroformate                                    |
|                                                                | Anisoyl chloride                                                              | Ethyl chlorocarbonate                                  |
|                                                                | Benzhydryl bromide<br>(diphenyl methyl bromide)                               | Ethylene oxide                                         |
|                                                                | Benzoyl chloride                                                              | Fumaryl chloride                                       |
|                                                                | Benzyl bromide                                                                | Iso-propylchloroformate                                |
|                                                                | Benzyl chloride                                                               | Methyl chloroformate                                   |
|                                                                | Benzyl chloroformate<br>(benzyl chlorocarbonate)                              | Methyl chlorocarbonate                                 |
|                                                                | Butyl acid phosphate                                                          | Propionyl chloride                                     |
|                                                                | Chloroacetyl chloride                                                         | Sodium fluorosilicate                                  |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |
|                                                                |                                                                               |                                                        |



Table 5.4 Cont'd

|                                               |                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                |
|-----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Chlorosilanes</b>                          | Allyl trichlorosilane<br>Amyl trichlorosilane<br>Butyl trichlorophenyl-trichlorosilane<br>Cyclohexyl trichlorosilane<br>Dichlorophenyl trichlorosilane<br>Diethyl trichlorosilane<br>Diphenyl dichlorosilane<br>Dodecyl trichlorosilane                                                                                            | Hexadecyl trichlorosilane<br>Hexyl trichlorosilane<br>Methyl trichlorosilane<br>Nonyl trichlorosilane<br>Octadecyl trichlorosilane<br>Octyl trichlorosilane<br>Phenyl trichlorosilane<br>Trimethyl trichlorosilane<br>Vinyl trichlorosilane                                                    |
| <b>Miscellaneous<br/>corrosive substances</b> | <i>Proprietary mixtures, e.g. cleaning, disinfecting, bleaching, degreasing solids or solutions, based on these chemicals are corrosive to a degree dependent upon dilution</i>                                                                                                                                                    |                                                                                                                                                                                                                                                                                                |
|                                               | Ammonium sulphide<br>Benzene sulphonyl chloride<br>Benzyl dimethylamine<br>Beryllium nitrate<br>Catechol<br>Chlorinated benzenes and toluenes<br>Chlorobenzaldehyde<br>Chlorocresols<br>Cresols<br>Cyclohexylamine<br>Dibenzylamine<br>Dichlorophenol<br>Diethyl sulphate<br>Diketene<br>Dimethyl sulphate<br>Hexamethylenediamine | Hydrazine<br>Hydrogen peroxide<br>Organic peroxides<br>Phenols<br>Silver nitrate<br>Soda lime<br>Sodium aluminate<br>Sodium amide<br>Sodium bisulphate<br>Sodium bisulphite<br>Sodium chromate and dichromate<br>Sodium hydride<br>Sodium pyrosulphate<br>Triethyltetramine<br>Tritolyl borate |

Table 5.5 Common industrial skin sensitizers

|                                            |                                                                                                                                                                                                                                                           |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Coal-tar and its direct derivatives</b> | Erio black<br>Hydron blue<br>Indanthrene violet, R.R.<br>Ionamine, A.S.<br>Malachite green<br>Metanil yellow<br>Nigrosine<br>Orange Y<br>Paramido phenol<br>Paraphenylendiamine<br>Pyrogene violet brown<br>Rosaniline<br>Safranine<br>Sulphanthrene pink |
| <b>Dyes</b>                                | <b>Dye intermediates</b>                                                                                                                                                                                                                                  |
| Amido-azo-benzene                          | Acridine and compounds                                                                                                                                                                                                                                    |
| Amido-azo-toluene                          | Aniline and compounds                                                                                                                                                                                                                                     |
| Aniline black                              | Benzanthrone and compounds                                                                                                                                                                                                                                |
| Auramine                                   | Benzidine and compounds                                                                                                                                                                                                                                   |
| Bismarck brown                             | Chloro compounds                                                                                                                                                                                                                                          |
| Brilliant indigo, 4 G.                     |                                                                                                                                                                                                                                                           |
| Chrysoidine                                |                                                                                                                                                                                                                                                           |
| Crystal and methyl violet                  |                                                                                                                                                                                                                                                           |

Table 5.5 Cont'd

Naphthalene and compounds  
Naphthylamines  
Nitro compounds

**Explosives**

Ammonium nitrate  
Dinitrophenol  
Dinitrotoluol  
Fulminate of mercury  
Hexanitrodiphenylamine  
Lead styphnate  
Picric acid and picrates  
Potassium nitrate  
Sensol  
Sodium nitrate  
Trinitromethylnitramine (Tetryl)  
Trinitrotoluene

**Insecticides**

Arsenic compounds<sup>(1)</sup>  
Creosote  
Fluorides<sup>(1)</sup>  
Lime<sup>(1)</sup>  
Mercury compounds<sup>(1)</sup>  
Nicotine  
Organic phosphates  
Petroleum distillates<sup>(1)</sup>  
Phenol compounds<sup>(1)</sup>  
Pyrethrum

**Natural resins**

Burgundy pitch  
Copal  
Dammar  
Japanese lacquer  
Pine rosin  
Wood rosin

**Oils**

Cashew nut oil<sup>(1)</sup>  
Coconut oil  
Coning oils (cellosolves, eugenols)  
Cutting oils (the inhibitor or antiseptic they contain)  
Essential oils of plants and flowers  
Linseed oil  
Mustard oil<sup>(1)</sup>  
Sulphonated tung oil

**Photographic developers**

Bichromates

Hydroquinone  
Metol  
*Para*-amido-phenol  
Paraformaldehyde  
Paraphenylenediamine  
Pyrogallol

**Plasticizers**

Butyl cellosolve stearate  
Diamyl naphthalene  
Dibutyl tin laurate  
Diocetylphthalate  
Methyl cellosolve oleate  
Methyl phthalylethylglycola  
Phenylsalicylate  
Propylene stearate  
Stearic acid  
Triblycol di-(2,ethyl butyrate)

**Rubber accelerators and anti-oxidants**

Guanidines  
Hexamethylene tetramine  
Mercapto benzo thiazole  
*Ortho*-toluidine  
*Para*-toluidine  
Tetramethyl thiuram monosulphide and disulphide  
Triethyl tri-methyl triamine

**Synthetic resins**

Acrylic  
Alkyd  
Chlorobenzols  
Chlorodiphenyls  
Chloro-naphthalenes  
Chlorophenols  
Cumaron  
Epoxyes  
Melamine formaldehyde  
Phenol formaldehyde  
Polyesters  
Sulphonamide formaldehyde  
Urea formaldehyde  
Urethane  
Vinyl

**Others**

Enzymes derived from *B. subtilis*

<sup>(1)</sup> Compounds which also act as primary irritants.

**Table 5.6 Some substances recognized as causing occupational asthma**

| <i>Substance</i>                                                                                                             | <i>Examples of use</i>                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Isocyanates                                                                                                                  | Plastic foam, synthetic inks, paints and adhesives                                                                                |
| Platinum salts                                                                                                               | Platinum refining workshops and some laboratories                                                                                 |
| Acid anhydride and amine hardening agents, including epoxy resin curing agents, e.g. ethylene diamine, triethylene tetramine | Adhesives, plastics, moulding resins and surfaces coatings                                                                        |
| Fumes from the use of resin (colophony) as a soldering flux                                                                  | The electronics industry                                                                                                          |
| Proteolytic enzymes                                                                                                          | Biological washing powders and the baking, brewing, fish, silk and leather industries                                             |
| Animals, including insects and other arthropods or their larval forms                                                        | Research and educational laboratories, pest control and fruit cultivation                                                         |
| Dusts from barley, oats, rye, wheat or maize, or meal or flour made from such grain                                          | The baking or flour milling industry or on farms                                                                                  |
| Antibiotics, e.g. cephalosporins, hydralizine, ampicillins, piperazine, spiramycin                                           | Manufacture, dispensing                                                                                                           |
| Cimetidine                                                                                                                   | Manufacture of cimetidine tablets                                                                                                 |
| Wood dusts; some hardwoods (e.g. iroko, mahogany); some softwoods (e.g. western red cedar)                                   | Furniture manufacture                                                                                                             |
| Ispaghula powder                                                                                                             | Manufacture of bulk laxatives                                                                                                     |
| Castor bean dust                                                                                                             | Processing                                                                                                                        |
| Ipecacuanha                                                                                                                  | Manufacture of ipecacuanha tablets                                                                                                |
| Azodicarbonamide                                                                                                             | Blowing agent in the manufacture of expanded foam plastics for wallcoverings, floor coverings, insulation and packaging materials |
| Glutaraldehyde                                                                                                               | Hospitals, laboratories, cooling tower systems and leather tanning                                                                |
| Persulphate salts and henna                                                                                                  | Manufacture of hair care products and their application                                                                           |
| Crustaceans                                                                                                                  | Fish and food processing industries                                                                                               |
| Reactive dyes                                                                                                                | Dyeing, printing and textile industries                                                                                           |
| Soya bean                                                                                                                    | Soya bean processing and food industries                                                                                          |
| Tea dust                                                                                                                     | Tea processing and food industries                                                                                                |
| Green coffee bean dust                                                                                                       | Coffee processing and food industries                                                                                             |
| Fumes from stainless steel welding                                                                                           | Stainless steel fabrication operations                                                                                            |
| Natural rubber latex                                                                                                         | Latex gloves, adhesives, surgical apparatus and appliances                                                                        |
| Water-mix metalworking fluids                                                                                                | Coolants in metalworking                                                                                                          |
| Certain cyanoacrylates                                                                                                       | Adhesives                                                                                                                         |
| Methyl methacrylate                                                                                                          | Adhesives                                                                                                                         |
| Diazonium salts                                                                                                              | Polymer manufacture                                                                                                               |
| Paraphenylenediamine                                                                                                         | Hair dyes and treatments                                                                                                          |
| Formaldehyde                                                                                                                 | Preserving, resin and foam manufacture                                                                                            |
| Cobalt                                                                                                                       | Hard metal manufacture and tools                                                                                                  |
| Nickel                                                                                                                       | Electroplating                                                                                                                    |
| Bromelein, papain                                                                                                            | Meat tenderizing                                                                                                                  |
| Amylase                                                                                                                      | Flour improver                                                                                                                    |
| Triglycidyl isocyanurate                                                                                                     | Polyester-based powder coatings                                                                                                   |
| Azodicarbonamide                                                                                                             | Plastics manufacture; flour improver                                                                                              |
| Butadiene diepoxide                                                                                                          | Polymer manufacture                                                                                                               |
| 2,3-epoxy-1-propanol (glycidol)                                                                                              | Oil stabilizer                                                                                                                    |

**Table 5.7 Typical effects of depleted oxygen levels in air**

| <i>Oxygen concentration (%)</i> | <i>Effect</i>                                            |
|---------------------------------|----------------------------------------------------------|
| 16–21                           | No noticeable effect                                     |
| 12–16                           | Increased respiration, slight diminution of coordination |
| 10–12                           | Loss of ability to think clearly                         |
| 6–10                            | Loss of consciousness, death                             |

Levels below 19.5% oxygen can have detrimental effects if the body is already under stress, e.g. at high altitudes. Exposures below 18% should not be permitted under any circumstance. Other chemicals, e.g. carbon monoxide, result in toxic anoxia due to damage of the body's oxygen transport or utilization mechanism.

### ***Anaesthetics and narcotics***

Anaesthetics and narcotics, e.g. hydrocarbons and certain derivatives such as the various chlorinated solvents or ether, exert a depressant action on the central nervous system.

### ***Systemic poisons***

Systemic poisons attack organs other than the initial site of contact. The critical organs are the kidneys, liver, blood and bone marrow.

### ***Respiratory fibrogens***

The hazard of particulate matter is influenced by the toxicity and size and morphology of the particle. Figure 5.2 gives typical particle size ranges for particles from various sources. The critical size of dust (and aerosol) particles is 0.5 to 7  $\mu\text{m}$ , since these can become deposited in the respiratory bronchioles and alveoli. If dust particles of specific chemicals, e.g. silica or the various grades of asbestos, are not cleared from the lungs then, over a period, scar tissue (collagen) may build up; this reduces the elasticity of the lungs and impairs breathing. The characteristic disease is classified as pneumoconiosis. Common examples are silicosis, asbestosis, coal pneumoconiosis and talc pneumoconiosis.

An appreciation of the composition and morphology of the dust is important in the assessment of hazard. Thus, among silica-containing compounds, crystalline silicates and amorphous silicas (silicon dioxide) are generally not considered fibrogenic, whereas free crystalline silica and certain fibrous silicates such as asbestos and talcs can cause disabling lung diseases. Table 5.8 indicates the approximate free silica content of various materials; Table 5.9 lists a range of silica-containing materials according to type.

### ***Carcinogens***

Cancer is a disorder of the body's control of the growth of cells. The disease may be genetic or influenced by life style or exposure to certain chemicals, termed carcinogens. For a list of examples of human chemical carcinogens, and the relevant target organs, refer to Table 5.10.

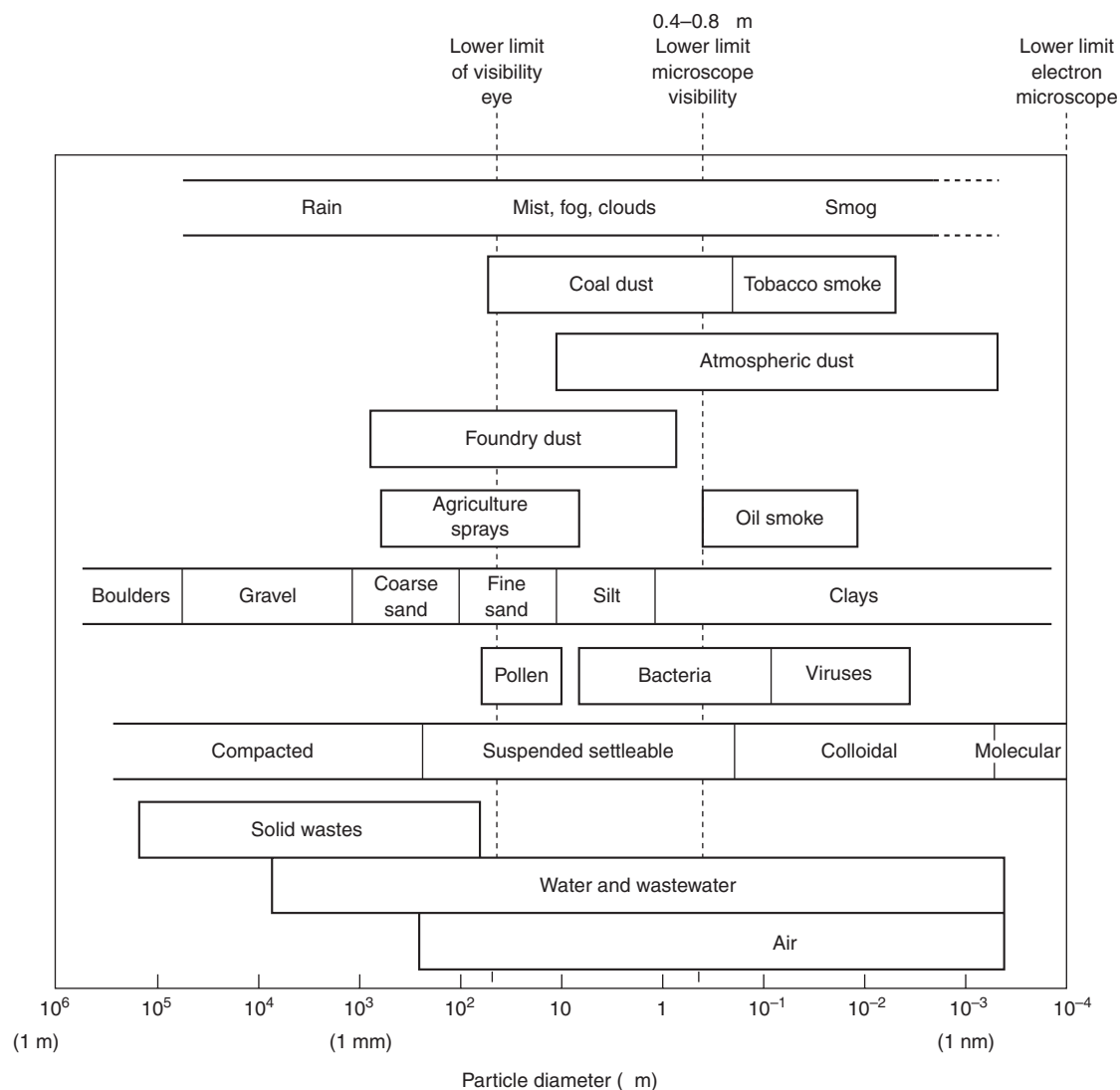


Figure 5.2 Typical particle size ranges

Table 5.8 Crystalline  $\text{SiO}_2$  in various materials

| Material                    | Normal range crystalline $\text{SiO}_2$ (%) |
|-----------------------------|---------------------------------------------|
| Foundry moulding sand       | 50–90                                       |
| Potteryware body            | 15–25                                       |
| Brick and tile compositions | 10–35                                       |
| Buffing wheel dressings     | 0–60                                        |
| Road rock                   | 0–80                                        |
| Limestone (agricultural)    | 0–3                                         |
| Feldspar                    | 12–25                                       |
| Clay                        | 0–40                                        |
| Mica                        | 0–10                                        |
| Talc                        | 0–5                                         |
| Slate and shale             | 5–15                                        |

**Table 5.9 Types of silica-containing dusts****Crystalline free silica** ( $\text{SiO}_2$ , including microcrystalline forms)

|                       |                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Chalcedony            | A heat-resistant, chemically inert form of microcrystalline quartz. A decorative material. Rare in industry.                                                                                                                                                                                                                                                                            |
| Chert                 | A microcrystalline form of silica. An impure form of flint used in abrasives.                                                                                                                                                                                                                                                                                                           |
| Cristobalite          | A crystalline form of free silica, extremely hard and inert chemically; very resistant to heat. Quartz in refractory bricks and amorphous silica in diatomaceous earth are altered to cristobalite when exposed to high temperatures (calcined). Cristobalite is extensively used in precision casting by the hot wax process, dental laboratory work, and certain speciality ceramics. |
| Flint                 | A microcrystalline form of native quartz, more opaque and granular than chalcedony. Used as an abrasive and in ceramics.                                                                                                                                                                                                                                                                |
| Jasper                | A microcrystalline impure form of silica similar to chert. Used for decorative purposes. Rare in industry.                                                                                                                                                                                                                                                                              |
| Quartz                | Vitreous, hard, chemically-resistant free silica, the most common form in nature. The main constituent in sandstone, igneous rocks, and common sands.                                                                                                                                                                                                                                   |
| Tridymite             | Vitreous, colourless form of free silica. Formed when quartz is heated to 870 C (1598 F).                                                                                                                                                                                                                                                                                               |
| Tripoli (rottenstone) | A porous siliceous rock resulting from the decomposition of chert or siliceous limestone. Used as a base in soap and scouring powders, in metal polishing, as a filtering agent, and in wood and paint fillers. A cryptocrystalline form of free silica.                                                                                                                                |

**Amorphous free silica** (Noncrystalline)

|                    |                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Diatomaceous earth | A soft, gritty amorphous silica composed of minute siliceous skeletons of small aquatic plants. Used in filtration and decoloration of liquids, insulation, filler in dynamite, wax, textiles, plastics, paint, and rubber. Calcined and flux-calcined diatomaceous earth contains appreciable amounts of cristobalite, and dust levels should be the same as for cristobalite. |
| Silica gel         | A regenerative absorbent consisting of the amorphous silica manufactured by the action of HCl on sodium silicate. Hard, glossy, quartz-like in appearance. Used in dehydrating and in drying and as a catalyst carrier.                                                                                                                                                         |

**Silicates** (compounds made up of silicon, oxygen and one or more metals with or without hydrogen. Asbestos dust is the most hazardous (page 148). Others, e.g. talc, mica, vermiculite, have caused a silicatoses on prolonged exposure.)

|                               |                                                                                                                                                                                                                                                                                                                    |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Asbestos                      | A hydrated magnesium silicate in fibrous form. The fibres are believed to be the more hazardous component of asbestos dust.                                                                                                                                                                                        |
| Clays                         | A great variety of aluminium-silicate bearing rocks, plastic when wet, hard when dry. Used in pottery, stoneware, tile, bricks, cements, fillers and abrasives. Kaolin is one type of clay. Some clay deposits may include appreciable amounts of quartz. Commercial grades of clays may contain up to 20% quartz. |
| Feldspar                      | Most abundant group of materials, composed of silicates of aluminium with sodium, potassium, calcium, and rarely barium. Most economically important mineral. Used for ceramics, glass, abrasive wheels, cements, insulation and fertilizer.                                                                       |
| Fuller's earth                | A hydrated silica-alumina compound, associated with ferric oxide. Used as a filter medium and as a catalyst and catalyst carrier and in cosmetics and insecticides.                                                                                                                                                |
| Kaolin                        | A type of clay composed of mixed silicates and used for refractories, ceramics, tile and stoneware.                                                                                                                                                                                                                |
| Mica                          | A large group of silicates of varying composition, but similar in physical properties. All have excellent cleavage and can be split into very thin sheets. Used in electrical insulation.                                                                                                                          |
| Portland cement               | Fine powder containing compounds of lime, alumina, silica and iron oxide. Used as a construction material.                                                                                                                                                                                                         |
| Silicon carbide (carborundum) | Bluish-black, very hard crystals. Used as an abrasive and refractory material.                                                                                                                                                                                                                                     |
| Talc                          | A hydrous magnesium silicate used in ceramics, cosmetics, paint and pharmaceuticals, and as a filler in soap, putty and plaster.                                                                                                                                                                                   |
| Vermiculite                   | An expanded mica (hydrated magnesium-aluminium-iron silicate). Used in lightweight aggregates, insulation, fertilizer and soil conditioners, as a filler in rubber and paints, and as a catalyst carrier.                                                                                                          |

**Table 5.10 Chemicals associated with cancer in humans (not all those listed are still in industrial use)****Chemicals and industrial processes which are carcinogenic for humans**

| <i>Substance or process</i>                                     | <i>Site affected and type of neoplasm</i>                                                                   |
|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| 4-Aminobiphenyl                                                 | Bladder – carcinoma                                                                                         |
| Arsenic and certain compounds                                   | Skin, lung, liver – carcinoma                                                                               |
| Asbestos                                                        | Respiratory tract – carcinoma<br>Pleura and peritoneum – mesothelioma<br>Gastrointestinal tract – carcinoma |
| Auramine manufacture                                            | Bladder – carcinoma                                                                                         |
| Benzene                                                         | Blood – leukaemia                                                                                           |
| Benzidene                                                       | Bladder – carcinoma                                                                                         |
| Bis (chloromethyl) ether and technical grade chloromethyl ether | Lung – carcinoma                                                                                            |
| Chlornaphazine                                                  | Bladder – carcinoma                                                                                         |
| Chromium and certain compounds                                  | Lung – carcinoma                                                                                            |
| Diethylstilbestrol                                              | Female genital tract – carcinoma (transplacental)                                                           |
| Haematite mining (underground)                                  | Lung – carcinoma                                                                                            |
| Isopropanol manufacture (strong acid process)                   | Respiratory tract – carcinoma                                                                               |
| Melphalan                                                       | Blood – leukaemia                                                                                           |
| Mustard gas                                                     | Respiratory tract – carcinoma                                                                               |
| 2-Naphthylamine                                                 | Bladder – carcinoma                                                                                         |
| Nickel refining                                                 | Respiratory tract – carcinoma                                                                               |
| Soots, tars, and mineral oils                                   | Skin, lung, bladder – carcinoma                                                                             |
| Vinyl chloride                                                  | Liver – angiosarcoma<br>Brain<br>Lung – carcinoma<br>Lymphatic system – lymphoma                            |

**Chemicals which are probably carcinogenic in humans**

| <i>Substance</i>                | <i>Site affected (human)</i>  |
|---------------------------------|-------------------------------|
| Acrylonitrile                   | Colon, lung                   |
| Aflatoxins                      | Liver                         |
| Amitrole                        | Various sites                 |
| Auramine                        | Bladder                       |
| Beryllium and certain compounds | Bone, lung                    |
| Cadmium and certain compounds   | Kidney, prostate, lung        |
| Carbon tetrachloride            | Liver                         |
| Chlorambucil                    | Blood                         |
| Cyclophosphamide                | Bladder, blood                |
| Dimethylcarbamoil chloride      |                               |
| Dimethyl sulphate               | Lung                          |
| Ethylene oxide                  | Gastrointestinal tract, blood |
| Iron dextran                    | Connective tissue             |
| Nickel and certain compounds    | Respiratory tract             |
| Oxymetholone                    | Liver                         |
| Phenacetin                      | Kidney, bladder               |
| Polychlorinated biphenyls       | Skin, various sites           |
| Thiotepa                        | Blood                         |

## Hazard assessment

Indicators of toxicity hazards include  $LD_{50}$ ,  $LC_{50}$ , plus a wide range of *in vitro* and *in vivo* techniques for assessment of skin and eye irritation, skin sensitization, mutagenicity, acute and chronic dermal and inhalation toxicity, reproductive toxicology, carcinogenicity etc.

The  $LD_{50}$  is the statistically derived single dosage of a substance that can be expected to cause death in 50% of the sample population. It is therefore an indicator of acute toxicity, usually determined by ingestion using rats or mice, although other animals may be used.  $LD_{50}$  is also determined by other routes, e.g. by skin absorption in rabbits. The values are affected by species, sex, age, etc.

The  $LC_{50}$  is the lethal concentration of chemical (e.g. in air or water) that will cause the death of 50% of the sample population. This is most appropriate as an indicator of the acute toxicity of chemicals in air breathed (or in water, for aquatic organisms). Table 5.11 illustrates the use of  $LD_{50}$  values to rank the toxicity of substances.

**Table 5.11 Toxicity rating system**

| Toxicity rating | Commonly used term    | $LD_{50}$<br>Single oral<br>dose for rats<br>(g/kg) | 4hr<br>Vapour exposure<br>causing 2 to 4 deaths<br>in 6-rat group (ppm) | $LD_{50}$<br>Skin for<br>rabbits<br>(g/kg) | Probable<br>lethal dose<br>for humans |
|-----------------|-----------------------|-----------------------------------------------------|-------------------------------------------------------------------------|--------------------------------------------|---------------------------------------|
| 1               | Extremely toxic       | $\leq 0.001$                                        | $< 10$                                                                  | $\leq 0.005$                               | Taste<br>(1 grain)                    |
| 2               | Highly toxic          | 0.001–0.05                                          | 10–100                                                                  | 0.005–0.043                                | 1 teaspoon<br>(4 ml)                  |
| 3               | Moderately toxic      | 0.05–0.5                                            | 100–1000                                                                | 0.044–0.340                                | 1 oz (30 g)                           |
| 4               | Slightly toxic        | 0.5–5.0                                             | 1000–10 000                                                             | 0.35–2.81                                  | 1 pint<br>(250 g)                     |
| 5               | Practically non-toxic | 5.0–15.0                                            | 10 000–100 000                                                          | 2.82–22.6                                  | 1 quart<br>(500 g)                    |
| 6               | Relatively harmless   | $> 15.0$                                            | $> 100\ 000$                                                            | $> 22.6$                                   | $> 1$ quart                           |

## Hygiene standards

Hygiene standards are employed as indicators of risk to man from inhalation of toxic or nuisance chemicals at work.

Some indication of risk of employee exposure to airborne chemicals can be gauged from an analysis of the level of exposure for comparison with known human dose/response data such as those for carbon monoxide and hydrogen sulphide listed in Tables 5.31 and 5.32. More commonly the reference is to published hygiene standards based on human epidemiology, animal data and extrapolations from information on related chemicals, with built-in safety factors. Table 5.12 lists hygiene standards published annually by the American Conference of Governmental Industrial Hygienists (ACGIH), known as threshold limit values (TLV), and the UK equivalents published by the Health and Safety Executive (HSE), known as Occupational Exposure Limits (OELs). The table is a useful first point of reference but the original publications should be consulted for most up-to-date values, an indication of proposed changes, and more detailed guidance on their interpretation. It is also important to consult the latest documentation explaining the toxicological background to the values.



### *Threshold limit values (TLV)*

These values represent airborne concentrations of substances to which it is believed that nearly all workers may be repeatedly exposed by inhalation day after day without adverse health effects. Because of the wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations below the TLV. A smaller percentage may experience aggravation of a pre-existing condition/illness. Age, genetic factors or personal habits may make some individuals hypersensitive. Physical factors, e.g. UV, ionizing radiation, humidity, abnormal atmospheric pressure (altitude), excessive temperatures, or overtime working may add stress to the body so that effects from exposure at a TLV may be altered. Therefore best occupational hygiene practice is to maintain levels of all airborne contaminants as low as is reasonably practicable.

There are three categories of TLV:

- 1 *Time-weighted average (TWA) TLV* – the time-weighted average concentration for a normal 8 hr work day and a 40 hr work week, to which it is believed that nearly all workers may be repeatedly exposed, day after day, without untoward effects. TWA TLVs permit excursions above the TLV provided that they are compensated for by equivalent excursions below the TLV during the work day. The excursion above the TLV is a rule of thumb, as explained in the source reference.
- 2 *Short-term exposure limit (STEL) TLV* – the concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TWA limit is not exceeded. A STEL is a 15 min TWA exposure which should not be exceeded at any time during the work day even if the TWA is within the TLV. It should not occur more than four times per day or without at least one hour between successive exposures.
- 3 *Ceiling TLV(C)* – the concentration that should not be exceeded during any part of the working exposure. If instantaneous monitoring is not possible then the TLV(C) can be assessed over a 15 min sampling period, except for those substances that may cause immediate irritation when exposures are short.

### *Occupational exposure limits (OEL)*

Occupational exposure limits for airborne contaminants are reviewed annually in the UK by the Health and Safety Executive. They are published as Guidance Note EH 40/-. The two types of exposure limit are:

*Long-term exposure limits.* These are concerned with the total intake of a contaminant (or contaminants) over a long period. As such they are appropriate for protecting workers against the effects of long-term exposure, or reducing the risks to an insignificant level.

*Short-term exposure limits.* These are concerned primarily with the avoidance of acute effects, or reducing the risk of the occurrence.

Long-term and short-term limits are expressed as time-weighted average concentrations. For a long-term limit the normal period is eight hours (although for vinyl chloride it is 1 year); for a short-term limit the normal period is 15 minutes.

Specific short-term exposure limits are listed by the HSE for those chemicals which pose a risk of acute effects such as eye irritation from brief exposures. For other chemicals a recommended

guideline for controlling short-term excursions is to restrict them to  $3 \times$  long-term exposure limit averaged over a 15 min period.

### *Percutaneous absorption*

For most chemicals, inhalation is the main route of entry into the body. Penetration via damaged skin (e.g. cuts, abrasions) should, however, be avoided. Certain chemicals (e.g. phenol, aniline, certain pesticides) can penetrate intact skin and so become absorbed into the body. This may occur through local contamination, e.g. from a liquid splash, or through exposure to high vapour concentrations. Special precautions to avoid skin contact are required with these chemicals and potential exposure via skin absorption has to be taken into account when assessing the adequacy of control measures.

Some chemicals able to penetrate intact skin are listed in Table 5.2.

### *MEL/OES*

In the UK (under the Control of Substances Hazardous to Health Regulations 1999) there are maximum exposure limits (MEL) and occupational exposure standards (OES):

*Maximum exposure limit (MEL)* – the maximum concentration of an airborne substance, averaged over a reference period, to which employees may be exposed by inhalation under any circumstance. Thus, exposure to a chemical assigned an MEL must be as low as is reasonably practicable and, in any case, below the MEL.

*Occupational exposure standard (OES)* – the concentration of an airborne substance, averaged over a reference period, at which, according to current knowledge, there is no evidence that it is likely to be injurious to employees if they are exposed by inhalation, day after day, to that concentration. Exposure to a chemical assigned an OES must be at no greater than that concentration but there is, under the UK Control of Substances Hazardous to Health Regulations, no duty to reduce it further. (Also under COSHH, if the OES is in fact exceeded but an employer has identified the reasons, and is taking appropriate action to remedy it as soon as reasonably practicable, control may be regarded as being adequate.) However,

- (a) exposure should preferably be reduced below the OES to ensure that the exposure of all personnel does not exceed it;
- (b) further application of good occupational hygiene principles to reduce exposure below the OES should not be discouraged.

### *The application of standards*

Caution is necessary in the application of control limits because of:

The effects of mixtures of chemicals, e.g. additive or synergistic.

The effects of extended working hours, exertion etc.

The variation between workers in susceptibility to the effects of chemical exposures, e.g. inherently or due to a pre-existing medical condition.

Changes in limits with increasing knowledge of toxicology.

With some asthmagens, respiratory sensitization may occur at atmospheric concentrations below published limits.

In any event, hygiene standards:

- (a) should not be used as an index of relative hazard or toxicity;
- (b) are not well-defined dividing lines between 'safe' and 'dangerous' airborne concentrations;
- (c) cannot be readily extrapolated to assess long-term, non-occupational exposures, e.g. to environmental pollutants.

### *Calculation of exposure*

(a) *Single substances.* Hygiene standards are quoted for pure substances. The 8 hr TWA is best assessed by personal dosimetry (Chapter 10) in which exposure is continuously monitored throughout the work day wherever the operator goes. When data are available on the individual fluctuations in exposure, e.g. from a variety of tasks, the 8 hr TWA exposure can be calculated as in the following example:

| <i>Working period</i> | <i>Exposure</i><br>(mg/m <sup>3</sup> ) |
|-----------------------|-----------------------------------------|
| 8.00–10.30            | 0.16                                    |
| 10.30–10.45           | 0.00                                    |
| 10.45–12.45           | 0.07                                    |
| 12.45–13.30           | 0.00                                    |
| 13.30–15.30           | 0.42                                    |
| 15.30–15.45           | 0.00                                    |
| 15.45–17.15           | 0.21                                    |

$$\begin{aligned}
 \text{8 hr TWA exposure} &= \frac{0.16 \times 2.5 + 0.07 \times 2 + 0.42 \times 2 + 0.21 \times 1.5 + 0 \times 1.25}{8} \\
 &= \frac{0.40 + 0.14 + 0.84 + 0.32}{8} \\
 &= 0.21 \text{ mg/m}^3
 \end{aligned}$$

(b) *Mixtures.* Often working practices result in exposures to mixtures of chemicals. The individual components of the mixture can act on the body independently, additively, synergistically or antagonistically. The ACGIH publication on TLVs and a Chemicals Industries Association booklet (see Bibliography) provide elementary advice on calculating hygiene standards for mixtures.

For compounds behaving additively, the relationship for compliance with the TLV of the mixture is given by

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \dots = 1$$

where  $C_1$ ,  $C_2$  and  $C_3$  are the concentrations of the different components and  $T_1$ ,  $T_2$  and  $T_3$  are the TLVs for each pure component.

*Example.* Air contains 200 ppm acetone (TLV = 750), 300 ppm sec-butyl acetate (TLV = 200) and 200 ppm of methyl ethyl ketone (TLV = 200):

$$\frac{\text{concentration}}{\text{TLV of mixture}} = \frac{200}{750} + \frac{300}{200} + \frac{200}{200} = 0.26 + 1.5 + 1 = 2.76$$

i.e. the TLV has been exceeded.

For independent effects, the relationship for compliance with the TLV of the mixture is given by:

$$\frac{C_1}{T_1} = 1, \quad \frac{C_2}{T_2} = 1, \quad \frac{C_3}{T_3} = 1 \text{ etc.}$$

*Example.* Air contains 0.10 mg/m<sup>3</sup> lead (TLV 0.15 mg/m<sup>3</sup>) and 0.9 mg/m<sup>3</sup> sulphuric acid (TLV 1 mg/m<sup>3</sup>):

$$\frac{0.10}{0.15} = 0.7 \quad \frac{0.9}{1.0} = 0.9$$

i.e. the TLV has not been exceeded.

For chemicals behaving antagonistically or synergistically, expert advice from a hygienist and toxicologist should be sought.

### *Biological exposure indices*

Exposure levels to certain chemicals can be monitored by determination of levels of the substance or its metabolites in exhaled breath or in body tissues or fluids such as urine, blood, hair, nails etc. For example, blood lead levels have long been used to determine operator exposure to this chemical. Alternatively, exposure to some chemicals can be gauged by measurement of modifications to critical biochemical constituents, e.g. changes in activity of a key enzyme, or physiological changes, e.g. vitalograph measurement. The advantage of biological monitoring over environmental analysis is that the former measures the actual amount of substance absorbed into the body and reflects the worker's individual responses and overall exposure. Shortcomings, however, include wide variation in individual responses to a given chemical; the unpopularity of invasive techniques; and, most importantly, the fact that it reflects a reaction to an exposure that has already occurred.

Biological exposure indices (BEI) published by the ACGIH are given in Table 5.13. BEIs represent the levels of determinant which are most likely to be observed in specimens collected from a healthy worker who has been exposed to chemicals to the same extent as a worker with inhalation exposure to the TLV. Due to biological variability it is possible for an individual's measurements to exceed the BEI without incurring increased health risk. If, however, levels in specimens obtained from a worker on different occasions persistently exceed the BEI, or if the majority of levels in specimens obtained from a group of workers at the same workplace exceed the BEI, the cause of the excessive values must be investigated and proper action taken to reduce the exposure.

BEIs apply to 8 hr exposures, five days a week. However, BEIs for altered working schedules can be extrapolated on pharmacokinetic and pharmacodynamic bases. BEIs should not be applied, either directly or through a conversion factor, to the determination of safe levels for non-occupational exposure to air and water pollutants, or food contaminants. The BEIs are not intended for use as a measure of adverse effects or for diagnosis of occupational illness.

There is also a framework for the use of biological monitoring in the UK. A biological monitoring guidance value has been set where it is likely to be of practical value, suitable monitoring methods exist and sufficient data are available.

Two types of value are quoted in Table 5.14:

A Health Guidance Value, set at a level at which there is no indication from the scientific evidence available that the substance is likely to be injurious to health.

A Benchmark Guidance value, set as a hygiene-based guidance value – actually a level which 90% of available validated data are below and therefore achievable by the great majority of industry with good workplace practices.

**Table 5.13 Adopted biological exposure determinants**

| <i>Chemical determinant</i>                                                                                                                     | <i>Sampling time</i>                                               | <i>Biological exposure indices</i>        | <i>Notation</i>    |
|-------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-------------------------------------------|--------------------|
| ACETONE<br>Acetone in urine                                                                                                                     | End of shift                                                       | 50 mg/l                                   | Ns                 |
| ACETYLCHOLINESTERASE<br>INHIBITING PESTICIDES<br>Cholinesterase activity in red blood cells                                                     | Discretionary                                                      | 70% of individuals baseline               | Ns                 |
| ANILINE<br>Total <i>p</i> -aminophenol in urine<br>Methemoglobin in blood                                                                       | End of shift<br>During or end of shift                             | 50 mg/g creatinine<br>1.5% of haemoglobin | Ns<br>B, Ns,<br>Sq |
| ARSENIC, ELEMENTAL<br>AND SOLUBLE INORGANIC COMPOUNDS<br>Inorganic arsenic plus methylated metabolites in urine                                 | End of workweek                                                    | 35 g/g As/l                               | B                  |
| BENZENE<br>S-Phenylmercapturic acid in urine<br><i>t,t</i> -Muconic acid in urine                                                               | End of shift<br>End of shift                                       | 25 g/g creatinine<br>500 g/g creatinine   | B<br>B             |
| CADMIUM AND<br>INORGANIC COMPOUND<br>Cadmium in urine<br>Cadmium in blood                                                                       | Not critical<br>Not critical                                       | 5 g/g creatinine<br>5 g/l                 | B<br>B             |
| CARBON DISULPHIDE<br>2-Thiothiazolidine-4-carboxylic acid (TTCA) in urine                                                                       | End of shift                                                       | 5 mg/g creatinine                         |                    |
| CARBON MONOXIDE<br>Carboxyhaemoglobin in blood<br>Carbon monoxide in end-exhaled air                                                            | End of shift<br>End of shift                                       | 3.5% of haemoglobin<br>20 ppm             | B, Ns<br>B, Ns     |
| CHLOROBENZENE<br>Total 4-chlorocatechol in urine<br>Total <i>p</i> -chlorophenol in urine                                                       | End of shift<br>End of shift                                       | 150 mg/g creatinine<br>25 mg/g creatinine | Ns<br>Ns           |
| CHROMIUM (VI), water-soluble fume<br>Total chromium in urine                                                                                    | Increase during shift<br>End of shift at end of workweek           | 10 g/g creatinine<br>30 g/g creatinine    | B<br>B             |
| COBALT<br>Cobalt in urine<br>Cobalt in blood                                                                                                    | End of shift at end of workweek<br>End of shift at end of workweek | 15 g/l<br>1 g/l                           | B<br>B, Sq         |
| <i>N,N</i> -DIMETHYLACETAMIDE<br><i>N</i> -Methylacetamide in urine                                                                             | End of shift at end of workweek                                    | 30 mg/g creatinine                        |                    |
| <i>N,N</i> -DEMETHYLFORMAMIDE (DMF)<br><i>N</i> -Methylformamide in urine<br><i>N</i> -Acetyl-S-( <i>N</i> -methyl-carbamoyl) cysteine in urine | End of shift<br>Prior to last shift of workweek                    | 15 mg/l<br>40 mg/l                        | Sq                 |

Table 5.13 Cont'd

| <i>Chemical determinant</i>                                                                                                   | <i>Sampling time</i>                                                                  | <i>Biological exposure indices</i>      | <i>Notation</i>  |
|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-----------------------------------------|------------------|
| 2-ETHOXYETHANOL (EGEE) and 2-ETHOXYETHYL ACETATE (EGEEA)<br>2-Ethoxyacetic acid in urine                                      | End of shift at end of workweek                                                       | 100 mg/g creatinine                     |                  |
| ETHYL BENZENE<br>Mandelic acid in urine<br>Ethyl benzene in end-exhaled air                                                   | End of shift at end of workweek                                                       | 1.5 g/g creatinine                      | Ns<br>Sq         |
| FLUORIDES<br>Fluorides in urine                                                                                               | Prior to shift<br>End of shift                                                        | 3 mg/g creatinine<br>10 mg/g creatinine | B, Ns<br>B, Ns   |
| FURFURAL<br>Total furoic acid in urine                                                                                        | End of shift                                                                          | 200 mg/g creatinine                     | B, Ns            |
| <i>n</i> -HEXANE<br>2,5-Hexanedione in urine<br><i>n</i> -Hexane in end-exhaled air                                           | End of shift                                                                          | 5 mg/g creatinine                       | Ns<br>Sq         |
| LEAD (see note below)<br>Lead in blood                                                                                        | Not critical                                                                          | 30 g/100 ml                             |                  |
| MERCURY<br>Total inorganic mercury in urine                                                                                   | Preshift                                                                              | 35 g/g creatinine                       | B                |
| Total inorganic mercury in blood                                                                                              | End of shift at end of workweek                                                       | 15 g/l                                  | B                |
| METHANOL<br>Methanol in urine                                                                                                 | End of shift                                                                          | 5 mg/l                                  | B, Ns            |
| METHEMOGLOBIN INDUCERS<br>Methemoglobin in blood                                                                              | During or end of shift                                                                | 1.5% of haemoglobin                     | B, Ns,<br>Sq     |
| 2-METHOXYETHANOL (EGME) and 2-METHOXYETHYL ACETATE (EGMEA)<br>2-Methoxyacetic acid in urine                                   | End of shift at end of workweek                                                       |                                         | Nq               |
| METHYL CHLOROFORM<br>Methyl chloroform in end-exhaled air<br>Trichloroacetic acid in urine<br>Total trichloroethanol in urine | Prior to last shift of workweek<br>End of workweek<br>End of shift at end of workweek | 40 ppm<br>10 mg/l<br>30 mg/l            | Ns, Sq<br>Ns, Sq |
| Total trichloroethanol in blood                                                                                               | End of shift at end of workweek                                                       | 1 mg/l                                  | Ns               |
| 4,4'-METHYLENE BIS(2-CHLOROANILINE) (MBOCA)<br>Total MBOCA in urine                                                           | End of shift                                                                          |                                         | Nq               |

Table 5.13 Cont'd

| <i>Chemical determinant</i>                                                               | <i>Sampling time</i>                                               | <i>Biological exposure indices</i>                  | <i>Notation</i> |
|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-----------------------------------------------------|-----------------|
| METHYL ETHYL KETONE (MEK)<br>MEK in urine                                                 | End of shift                                                       | 2 mg/l                                              |                 |
| METHYL ISOBUTYL KETONE (MIBK)<br>MIBK in urine                                            | End of shift                                                       | 2 mg/l                                              |                 |
| NITROBENZENE<br>Total <i>p</i> -nitrophenol in urine                                      | End of shift at end of workweek                                    | 5 mg/g creatinine                                   | Ns              |
| Methemoglobin in blood                                                                    | End of shift                                                       | 1.5% of haemoglobin                                 | B, Ns, Sq       |
| PARATHION<br>Total <i>p</i> -nitrophenol in urine<br>Cholinesterase activity in red cells | End of shift<br>Discretionary                                      | 0.5 mg/g creatinine<br>70% of individual's baseline | Ns<br>B, Ns, Sq |
| PENTACHLOROPHENOL (PCP)<br>Total PCP in urine                                             | Prior to last shift of workweek                                    | 2 mg/g creatinine                                   | B               |
| Free PCP in plasma                                                                        | End of shift                                                       | 5 mg/l                                              | B               |
| PERCHLOROETHYLENE<br>Perchloroethylene in end-exhaled air<br>Perchloroethylene in blood   | Prior to last shift of workweek<br>Prior to last shift of workweek | 5 ppm<br>0.5 mg/l                                   |                 |
| Trichloroacetic acid in urine                                                             | End of shift at end of workweek                                    | 3.5 mg/l                                            | Ns, Sq          |
| PHENOL<br>Total phenol in urine                                                           | End of shift                                                       | 250 mg/g creatinine                                 | B, Ns           |
| STYRENE<br>Manelic acid in urine                                                          | End of shift<br>Prior to next shift                                | 800 mg/g creatinine<br>300 mg/g creatinine          | Ns<br>Ns        |
| Phenylglyoxlic acid in urine                                                              | End of shift<br>Prior to next shift                                | 240 mg/g creatinine<br>100 mg/g creatinine          | Ns              |
| Styrene in blood                                                                          | End of shift<br>Prior to next shift                                | 0.55 mg/l<br>0.02 mg/l                              | Sq<br>Sq        |
| TETRAHYDROFURAN<br>Tetrahydrofuran in urine                                               | End of shift                                                       | 8 mg/l                                              |                 |
| TOLUENE<br><i>o</i> -Cresol in urine<br>Hippuric acid in urine<br>Toluene in blood        | End of shift<br>End of shift<br>Prior to last shift of workweek    | 0.5 mg/l<br>1.6 g/g creatinine<br>0.05 mg/l         | B<br>B, Ns      |
| TRICHLOROETHYLENE<br>Trichloroacetic acid in urine                                        | End of workweek                                                    | 100 mg/g creatinine                                 | Ns              |
| Trichloroacetic acid and trichlorethanol in urine                                         | End of shift at end of workweek                                    | 300 mg/g creatinine                                 | Ns              |
| Free trichloroethanol in blood                                                            | End of shift at end of workweek                                    | 4 mg/l                                              | Ns              |

**Table 5.13 Cont'd**

| <i>Chemical determinant</i>                                | <i>Sampling time</i>            | <i>Biological exposure indices</i> | <i>Notation</i> |
|------------------------------------------------------------|---------------------------------|------------------------------------|-----------------|
| Trichloroethylene in blood                                 |                                 |                                    | Sq              |
| Trichloroethylene in end-exhaled air                       |                                 |                                    | Sq              |
| VANADIUM PENTOXIDE<br>Vanadium in urine                    | End of shift at end of workweek | 50 g/g creatinine                  | Sq              |
| XYLENES (technical-grade)<br>Methylhippuric acids in urine | End of shift                    | 1.5 g/g creatinine                 |                 |

<sup>1</sup>Women of child-bearing potential, whose blood Pb exceeds 10 g/dl are at risk of delivering a child with a blood Pb over the current Centres for Disease Control guidelines of 10 g/dl. If the blood Pb of such children remains elevated, they may be at increased risk of cognitive deficits. The blood Pb of these children should be closely monitored and appropriate steps should be taken to minimize the child's exposure to environmental lead. (CDC Preventing Lead Poisoning in Young Children, October 1991; see BEI and TLV documentation for lead.)

#### *Notations*

'B' = background

The determinant may be present in biological specimens collected from subjects who have not been occupationally exposed, at a concentration which could affect interpretation of the result. Such background concentrations are incorporated in the BEI value.

'Nq' = non-quantitative

Biological monitoring should be considered for this compound based on the review; however, a specific BEI could not be determined due to insufficient data.

'Ns' = non-specific

The determinant is non-specific, since it is also observed after exposure to other chemicals.

'Sq' = semi-quantitative

The biological determinant is an indicator of exposure to the chemical, but the quantitative interpretation of the measurement is ambiguous. These determinants should be used as a screening test if a quantitative test is not practical or as a confirmatory test if the quantitative test is not specific and the origin of the determinant is in question.

It is essential to consult the specific BEI documentation before designing biological monitoring protocols and interpreting BEIs.

(Biological limits are also in force for lead and its compounds under the Control of Lead at Work Regulations 1998; different blood lead action, and suspension from work, levels apply to women of reproductive capacity, young persons and other employees.

Biological monitoring of cadmium workers is also recommended; guidance on interpretation of results is given in EH1 – Cadmium: health and safety precautions.)

#### *Odour thresholds*

Some materials possess low odour thresholds: their smell gives warning of impending danger. Others possess odour thresholds well in excess of the hygiene standard. Examples are included in Table 5.12.

Reliance on the nose as an indicator, however, can be hazardous since:

Untrained exposees may not understand the significance of an odour.

Some materials with low odour thresholds may paralyse the olfactory nerves and cause the sense of smell to be lost within minutes (e.g. hydrogen sulphide).

Some materials are odourless (e.g. nitrogen).

Some materials, such as arsine, phosphine, toluene di-isocyanate and stibine, may be present in concentrations in excess of their hygiene standards yet undetectable by smell.

Published odour threshold values vary widely from source to source.



**Table 5.14 UK biological monitoring guidance values**

| <i>Substance</i>                               | <i>Biological monitoring guidance values</i>                                                            | <i>Monitoring schedule</i>                                           |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Butan-2-one                                    | 70 mol butan-2-one/l in urine (HGV)                                                                     | Post shift                                                           |
| 2-Butoxyethanol                                | 240 mmol butoxyacetic acid/mol creatinine in urine (HGV)                                                | Post shift                                                           |
| <i>N,N</i> -Dimethylacetamide                  | 100 mmol <i>N</i> -methyl acetamide/mol creatinine in urine (HGV)                                       | Post shift                                                           |
| Carbon monoxide                                | 30 ppm carbon monoxide in end-tidal breath (HGV)                                                        | Post shift                                                           |
| Dichloromethane                                | 30 ppm carbon monoxide in end-tidal breath (HGV)                                                        | Post shift                                                           |
| Lindane ( $\gamma$ BHC (ISO))                  | 35 nmol/l (10 $\mu$ g/l) of Lindane in whole blood (equivalent to 70 nmol/l) of Lindane in plasma (BGV) | Random                                                               |
| MbOCA (2,2'-dichloro-4,4'-methylene dianiline) | 15 mol total MbOCA/mol creatinine in urine (BGV)                                                        | Post shift                                                           |
| Mercury                                        | 20 mol mercury/mol creatinine in urine (HGV)                                                            | Random                                                               |
| 4,4'-Methylenedianiline (MDA)                  | 50 mol total MDA/mol creatinine in urine (BGV)                                                          | Post shift for inhalation and pre-shift next day for dermal exposure |
| 4-Methylpentan-2-one                           | 20 mol 4-methylpentan-2-one/l in urine (HGV)                                                            | Post shift                                                           |

HGV = Health Guidance Value  
BGV = Benchmark Guidance Value

Workers may become acclimatized to a commonly-occurring odour, or be suffering temporarily from an impaired sense of smell, e.g. due to a cold.  
The odour of a toxic chemical may be masked by the odour from another substance, or a mixture.

## Risk assessment of carcinogens

Arguably, risk assessment from exposure to carcinogens merits special consideration because of the low levels of exposure capable of producing an adverse response in certain individuals coupled with the often long time-lag (latency period) between exposure and onset of disease.

There are several formal lists of carcinogens. Thus, in the UK under the Control of Substances Hazardous to Health Regulations 1999 (see later) carcinogens are defined as:

Any substance or preparation which if classified in accordance with the classification provided for by regulation 5 of the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 ('CHIPS') as amended would be in the category of danger, carcinogenic (category 1) or carcinogenic (category 2).

Substances listed in Table 5.15.

**Table 5.15 Substances and processes to which the definition of 'carcinogen' relates**


---

|                                                                                                              |
|--------------------------------------------------------------------------------------------------------------|
| Aflatoxins                                                                                                   |
| Arsenic                                                                                                      |
| Auramine manufacture                                                                                         |
| Calcining, sintering or smelting of nickel copper matte or acid leaching or electrorefining of roasted matte |
| Coal soots, coal tar, pitch and coal tar fumes                                                               |
| Hardwood dusts                                                                                               |
| Isopropyl alcohol manufacture (strong acid process)                                                          |
| Leather dust in boot and shoe manufacture, arising during preparation and finishing                          |
| Magenta manufacture                                                                                          |
| Mustard gas ( $\beta$ , $\beta'$ -dichlorodiethyl sulphide)                                                  |
| Rubber manufacturing and processing giving rise to rubber process dust and rubber fume                       |
| Used engine oils                                                                                             |

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Substances or preparations requiring to be labelled with the risk phrase 'R45' (may cause cancer) or 'R49' (may cause cancer by inhalation) under 'CHIPS' are listed in Table 5.16 after the 5th edition of the Approved Supply List (Information approved for the classification and labelling of substances and preparations dangerous for supply). This list excludes certain coal and oil-based substances which attract the phrase 'R45' only when they contain a certain percentage of a marker substance (e.g. benzene).

A summary of the evaluation of carcinogenic risks to humans by the International Agency for Research on Cancer is given in Table 5.17 together with the IARC reference. IARC classify carcinogens into four groups thus:

**Group 1:** The agent (mixture) is carcinogenic to humans. The exposure circumstance entails exposures that are carcinogenic to humans.

**Group 2:** (two classifications):

**Group 2A:** The agent (mixture) is probably carcinogenic to humans. The exposure circumstance entails exposures that are probably carcinogenic to humans.

**Group 2B:** The agent (mixture) is possibly carcinogenic to humans. The exposure circumstance entails exposures that are possibly carcinogenic to humans.

**Group 3:** The agent (mixture, or exposure circumstance) is unclassifiable as to carcinogenicity in humans.

**Group 4:** The agent (mixture, or exposure circumstance) is probably not carcinogenic to humans.

Table 5.17 lists only Groups 1 and 2.

## Risk control

Exposures to chemicals, resulting in toxic effects or oxygen-deficient atmospheres, may arise in a variety of industrial situations. A summary of common sources is given in Table 5.18: clearly this is not exhaustive since exposure may result whenever materials are mixed, machined, heated, dispersed or otherwise processed or used.

The precautions naturally vary in each case. For example, to avoid improper admixture of chemicals will require:

- Adequate training, instruction and supervision of workers.
- Identification of chemicals by name and code number.
- Segregated storage of incompatible substances.

**Table 5.16 Substances assigned 'R45' or 'R49' risk phrases**

*Substances with the risk phrase 'R45' (may cause cancer)*

Acrylamide  
 Acrylonitrile  
 5-Allyl-1,3-benzodioxide  
 4-Aminoazobenzene  
 4-Aminobiphenyl\* (4-Aminodiphenyl\*)  
 Salts of 4-Aminobiphenyl\* (salts of 4-Aminodiphenyl\*)  
 4-Amino-3-fluorophenol  
 Arsenic acid and its salts  
 Arsenic pentoxide  
 Arsenic trioxide  
 Asbestos (all types)  
 Azobenzene  
 Benzene  
 Benzidine\*  
 Salts of benzidine\*  
 Benzidine azo dyes (except those specified elsewhere in the Approved Supply List)  
 Benzo-(a)-anthracene  
 Benzo-(a)-pyrene  
 Benzo-(e)-pyrene  
 Benzo-(b)-fluoranthene  
 Benzo-(j)-fluoranthene  
 Benzo-(k)-fluoranthene  
 Beryllium compounds (except aluminium beryllium silicates)  
 Bis(chloromethyl)ether (BCME)  
 Butane [1], isobutane [2], containing  $\geq 0.1\%$  butadiene  
 Buta-1,3-diene  
 Cadmium chloride  
 Cadmium fluoride  
 Cadmium sulphate  
 Calcium chromate  
 Captafol (ISO)  
 Carbadox (INN)  
 Chloroaniline  
 2-Chloroallyl diethyldithiocarbamate (Sulfallate ISO)  
 Chlorodimethyl ether  
 1-Chloro-2,3-epoxypropane (epichlorohydrin)  
 Chromium III chromate (chromic chromate)  
 Chryene  
 CI Basic Red 9  
 CI Direct Black 38  
 CI Direct Blue 6  
 CI Direct Red 28  
 CI Disperse Blue 1  
 Clarified oils (petroleum), catalytic cracked  
 Clarified oils (petroleum), hydrodesulphurized catalytic cracked  
 Cobalt dichloride  
 Cobalt sulphate  
 Coke (coal tar), high temperature pitch  
 Coke (coal tar), mixed coal-high temperature pitch  
 Coke (coal tar), low temperature, high temperature pitch  
 Diaminotoluene  
 o-Dianisidine  
 Salts of o-dianisidine  
 o-Dianisidine-based azodyes  
 Diarsenic trioxide  
 Diazomethane  
 Dibenz(a,h)anthracene  
 1,2-Dibromo-3-chloropropane

**Table 5.16 Cont'd**


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1,2-Dibromoethane (ethylene dibromide)  
 3,3'-Dichlorobenzidine  
 Salts of 3,3'-dichlorobenzidine  
 1,4-Dichlorobut-2-ene  
 1,2-Dichloroethane (ethylene dichloride)  
 2,2'-Dichloro-4,4'-methylenedianiline (MbOCA)  
 Salts of 2,2-dichloro-4,4'-methylenedianiline  
 1,3-Dichloro-2-propanol  
 1,2:3,4 Diepoxybutane  
 Diethyl sulphate  
 3,3'-Dimethylbenzidine (*o*-tolidine)  
 Salts of 3,3'-dimethylbenzidine (salts of *o*-tolidine)  
 Dimethylcarbamoyl chloride  
 1,2-Dimethylhydrazine  
*N,N*-Dimethylhydrazine  
 Dimethylnitrosamine (*N*-nitroso dimethylamine)  
 Dimethylsulphamoyl chloride  
 Dimethyl sulphate  
 2,6-dinitrotoluene  
 1,2-diphenyl hydrazine  
 Disodium [5-((4'-((2,6-hydroxy-3-((2-hydroxy-5-sulphophenyl)azo)phenyl)azo)  
 (1,1'-biphenyl)-4-yl)azo)salicylato(4)cuprate(2-)  
 Distillates (petroleum), intermediate vacuum  
 Distillates (petroleum), petroleum residues vacuum  
 Distillates (petroleum), chemically neutralized heavy paraffinic  
 Distillates (petroleum), hydrodesulphurized light catalytic cracked  
 Distillates (petroleum), hydrodesulphurized full-range middle  
 Distillates (petroleum), light paraffinic  
 Distillates (petroleum), light vacuum  
 Distillates (petroleum), vacuum  
 Distillates (petroleum), hydrodesulphurized middle coker  
 Distillates (petroleum), heavy naphthenic  
 Distillates (petroleum), heavy steam cracked  
 Distillates (petroleum), acid-treated light naphthenic  
 Distillates (petroleum), acid-treated light paraffinic  
 Distillates (petroleum), chemically neutralized light paraffinic  
 Distillates (petroleum), chemically neutralized heavy naphthenic  
 Distillates (petroleum), chemically neutralized light naphthenic  
 Distillates (petroleum), light catalytic cracked  
 Distillates (petroleum), intermediate catalytic cracked  
 Distillates (petroleum), light thermal cracked  
 Distillates (petroleum), light steam-cracked naphtha  
 Distillates (petroleum), cracked steam-cracked petroleum distillate  
 Distillates (petroleum), hydrodesulphurized thermal cracked middle  
 Distillates (petroleum), acid-treated heavy paraffinic  
 Distillates (petroleum), light catalytic cracked, thermally degraded  
 Distillates (petroleum), light naphthenic  
 Distillates (coal tar), benzole fraction  
 Distillates (coal tar), heavy oils  
 Distillates (petroleum), intermediate catalytic cracked, thermally degraded  
 Distillates (petroleum), acid treated heavy, naphthenic  
 Distillates (petroleum), heavy catalytic cracked  
 Distillates (petroleum), heavy thermal cracked  
 Distillates (petroleum), heavy paraffinic  
 Distillates (petroleum), hydrodesulphurized intermediate catalytic cracked  
 Distillates (petroleum), hydrodesulphurized heavy catalytic cracked  
 1,2-Epoxypropane  
 2,3 Epoxypropan-1-ol  
 Erionite

Table 5.16 Cont'd

Ethyleneimine  
 Ethylene oxide  
 Extracts (petroleum), heavy naphthenic distillate solvent  
 Extracts (petroleum), heavy paraffinic distillate solvent  
 Extracts (petroleum), light naphthenic distillate solvent  
 Extracts (petroleum), light paraffinic distillate solvent  
 Extracts (petroleum), light vacuum gas oil solvent  
 Fuel oil no. 6  
 Fuel oil, heavy, high sulphur  
 Fuel oil, residues—straight-run gas oils, high sulphur  
 Fuel oil, residual  
 Gas oils (petroleum), thermal cracked, hydrodesulphurized  
 Gas oils (petroleum), heavy atmospheric  
 Gas oils (petroleum), hydrodesulphurized coker heavy vacuum  
 Gas oils (petroleum), steam cracked  
 Gas oils (petroleum), hydrodesulphurized heavy vacuum  
 Gas oils (petroleum), heavy vacuum  
 Gas oils (petroleum), light vacuum, thermal-cracked hydrodesulphurized  
 Gas oils (petroleum), hydrotreated vacuum  
 Gas oils (petroleum), catalytic-cracked naphtha depropanizer overhead, C<sub>3</sub>-rich acid-free  
 Gasoline, coal solvent extn, hydrocracked naphtha  
 Hexachlorobenzene  
 Hexamethylphosphoric triamide  
 Hydrazine  
 Salts of hydrazine  
 Hydrazine bis (3-carboxy-4-hydroxybenzene sulphonate)  
 Hydrazobenzene  
 Hydrocarbons C<sub>26–55</sub>, aromatic-rich  
 Lead hydrogen arsenate  
 2-Methylaziridine  
 4,4'-Methylene dianiline (4,4'-diaminodiphenylmethane)  
 4,4'-Methylenedi-*o*-toluidine  
 Methyl acrylamidomethoxyacetate (containing ≥0.1% acrylamide)  
 Methyl acrylamidoglycolate (containing ≥0.1% acrylamide)  
 2-Methoxyaniline  
 4-Methyl-phenylenediamine (2,-4-toluenediamine)  
 1-Methyl-3-nitro-1-nitrosoguanidine  
 Methyl-onn-azoxymethyl acetate (Methyl azoxy methyl acetate)  
 2-Naphthylamine\*  
 Salts of 2-naphthylamine\*  
 5-Nitroacenaphthene  
 2-Nitroanisole  
 4-Nitrobiphenyl\* (4-Nitrodiphenyl\*)  
 Nitrofen (ISO)  
 2-Nitronaphthalene  
 2-Nitropropane  
*N*-Nitrosodipropylamine  
 2,2'-(Nitrosoimino) bis ethanol  
 Petroleum gases, liquefied (various)  
 Potassium bromate  
 1,3-Propanesultone  
 3-Propanolide (Propiolactone)  
 Residual oils (petroleum)  
 Residues (petroleum), coker scrubber, condensed-ring-arom-containing  
 Residues (petroleum), hydrogenated steam-cracked naphtha  
 Residues (petroleum), atm tower  
 Residues (petroleum), vacuum, light  
 Residues (petroleum), steam-cracked naphtha distn  
 Residues (petroleum), steam cracked

**Table 5.16 Cont'd**


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|                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Residues (petroleum), heavy coker and light vacuum                                                                                                                                                                                                                                                                                             |
| Residues (petroleum), catalytic reformer fractionator                                                                                                                                                                                                                                                                                          |
| Residues (petroleum), hydrodesulphurized atmospheric tower                                                                                                                                                                                                                                                                                     |
| Residues (petroleum), topping plant, low sulphur                                                                                                                                                                                                                                                                                               |
| Residues (petroleum), heavy coker gas oil and vacuum gas oil                                                                                                                                                                                                                                                                                   |
| Residues (petroleum), thermal cracked                                                                                                                                                                                                                                                                                                          |
| Residues (petroleum), catalytic reformer fractionator residue distillation                                                                                                                                                                                                                                                                     |
| Residues (petroleum), catalytic cracking                                                                                                                                                                                                                                                                                                       |
| Residues (petroleum), steam-cracked light                                                                                                                                                                                                                                                                                                      |
| Residues (petroleum), hydrocracked                                                                                                                                                                                                                                                                                                             |
| Residues (petroleum), light vacuum                                                                                                                                                                                                                                                                                                             |
| Residues (petroleum), steam-cracked heat-soaked naphtha                                                                                                                                                                                                                                                                                        |
| Residues (petroleum), steam cracked                                                                                                                                                                                                                                                                                                            |
| Residues (petroleum), steam cracked, distillates                                                                                                                                                                                                                                                                                               |
| Residues (petroleum), atmospheric                                                                                                                                                                                                                                                                                                              |
| Residues, steam cracked, thermally treated                                                                                                                                                                                                                                                                                                     |
| Strontium chromate                                                                                                                                                                                                                                                                                                                             |
| Styrene oxide                                                                                                                                                                                                                                                                                                                                  |
| Tar, brown-coal                                                                                                                                                                                                                                                                                                                                |
| Tar, brown-coal, low temperature                                                                                                                                                                                                                                                                                                               |
| Tar, coal, low temperature                                                                                                                                                                                                                                                                                                                     |
| Tar, coal, high temperature                                                                                                                                                                                                                                                                                                                    |
| Tar, coal                                                                                                                                                                                                                                                                                                                                      |
| 1,4,5,8-tetraamino-anthraquinone                                                                                                                                                                                                                                                                                                               |
| Toluene-2,4-diammonium sulphate (4-methyl- <i>m</i> -phenylenediamine sulphate)                                                                                                                                                                                                                                                                |
| <i>o</i> -Toluidine                                                                                                                                                                                                                                                                                                                            |
| <i>o</i> -Toluidine-based azodyes                                                                                                                                                                                                                                                                                                              |
| Thioacetamide                                                                                                                                                                                                                                                                                                                                  |
| 4- <i>o</i> -Tolyazo- <i>o</i> -toluidine                                                                                                                                                                                                                                                                                                      |
| <i>a,a,a</i> -Trichlorotoluene                                                                                                                                                                                                                                                                                                                 |
| Urethane (INN)                                                                                                                                                                                                                                                                                                                                 |
| Vinyl chloride (Chloroethylene)                                                                                                                                                                                                                                                                                                                |
| Zinc chromates (including zinc potassium chromate)                                                                                                                                                                                                                                                                                             |
| <i>Substances with the risk phrase 'R49' (may cause cancer by inhalation)</i>                                                                                                                                                                                                                                                                  |
| Beryllium                                                                                                                                                                                                                                                                                                                                      |
| Beryllium compounds with the exception of aluminium beryllium silicates                                                                                                                                                                                                                                                                        |
| Cadmium oxide                                                                                                                                                                                                                                                                                                                                  |
| Cadmium sulphate                                                                                                                                                                                                                                                                                                                               |
| Chromium (VI) compounds (with the exception of barium chromate and of compounds specified elsewhere in the Approved Supply List)                                                                                                                                                                                                               |
| Chromium trioxide                                                                                                                                                                                                                                                                                                                              |
| Chromyl chloride (chromic oxychloride)                                                                                                                                                                                                                                                                                                         |
| Dinickel trioxide                                                                                                                                                                                                                                                                                                                              |
| Nickel dioxide                                                                                                                                                                                                                                                                                                                                 |
| Nickel monoxide                                                                                                                                                                                                                                                                                                                                |
| Nickel subsulphide                                                                                                                                                                                                                                                                                                                             |
| Nickel sulphide                                                                                                                                                                                                                                                                                                                                |
| Potassium chromate                                                                                                                                                                                                                                                                                                                             |
| Potassium dichromate                                                                                                                                                                                                                                                                                                                           |
| Refractory ceramic fibres or special purpose fibres, with the exception of those specified elsewhere in the Approved Supply List (man-made vitreous (silicate) fibres with random orientation with alkaline oxide and alkali earth oxide (Na <sub>2</sub> O + K <sub>2</sub> O + CaO + MgO + BaO) content less than or equal to 18% by weight) |
| The classification as a carcinogen need not apply to fibres with a length weighted geometric mean diameter less two standard errors greater than 6 μm                                                                                                                                                                                          |
| Sodium dichromate                                                                                                                                                                                                                                                                                                                              |
| Sodium dichromate dihydrate                                                                                                                                                                                                                                                                                                                    |

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\* The manufacture and use of these substances, or any substance containing them, in concentrations equal to or greater than 0.1% by weight, is prohibited in the UK (COSHH Reg. 4(1)).

**Table 5.17 Evaluation of carcinogenic risks to humans by the IARC, as at 2000****Group 1: Carcinogenic to humans (78)***Agents and groups of agents*

Aflatoxins, naturally occurring [1402-68-2] (Vol. 56; 1993)

4-Aminobiphenyl [92-67-1] (Vol. 1, Suppl. 7; 1987)

Arsenic [7440-38-2] and arsenic compounds (Vol. 23, Suppl. 7; 1987)

(NB: This evaluation applies to the group of compounds as a whole and not necessarily to all individual compounds within the group)

Asbestos [1332-21-4] (Vol. 14, Suppl. 7; 1987)

Azathioprine [446-86-6] (Vol. 26, Suppl. 7; 1987)

Benzene [71-43-2] (Vol. 29, Suppl. 7; 1987)

Benzidine [92-87-5] (Vol. 29, Suppl. 7; 1987)

Beryllium [7440-41-7] and beryllium compounds (Vol. 58; 1993)

(NB: Evaluated as a group)

*N,N*-Bis(2-chloroethyl)-2-naphthylamine (Chlornaphazine) [494-03-1] (Vol. 4, Suppl. 7; 1987)

Bis(chloromethyl)ether [542-88-1] and chloromethyl methyl ether [107-30-2] (technical-grade)

(Vol. 4, Suppl. 7; 1987)

1,4-Butanediol dimethanesulfonate (Busulphan; Myleran) [55-98-1] (Vol. 4, Suppl. 7; 1987)

Cadmium [7440-43-9] and cadmium compounds (Vol. 58; 1993)

(NB: Evaluated as a group)

Chlorambucil [305-03-3] (Vol. 26, Suppl. 7; 1987)

1-(2-Chloroethyl)-3-(4-methylcyclohexyl)-1-nitrosourea (Methyl-CCNU; Semustine) [13909-09-6] (Suppl. 7; 1987)

Chromium[VI] compounds (Vol. 49; 1990)

(NB: Evaluated as a group)

Cyclosporin [79217-60-0] (Vol. 50; 1990)

Cyclophosphamide [50-18-0] [6055-19-2] (Vol. 26, Suppl. 7; 1987)

Diethylstilboestrol [56-53-1] (Vol. 21, Suppl. 7; 1987)

Epstein-Barr virus (Vol. 70; 1997)

Erionite [66733-21-9] (Vol. 42, Suppl. 7; 1987)

Ethylene oxide [75-21-8] (Vol. 60; 1994)

(NB: Overall evaluation upgraded from 2A to 1 with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)

Etoposide [33419-42-0] in combination with cisplatin and bleomycin (Vol. 76; 2000)

[Gamma Radiation: see X- and Gamma (g)-Radiation]

*Helicobacter pylori* (infection with) (Vol. 61; 1994)

Hepatitis B virus (chronic infection with) (Vol. 59; 1994)

Hepatitis C virus (chronic infection with) (Vol. 59; 1994)

Human immunodeficiency virus type 1 (infection with) (Vol. 67; 1996)

Human papillomavirus type 16 (Vol. 64; 1995)

Human papillomavirus type 18 (Vol. 64; 1995)

Human T-cell lymphotropic virus type I (Vol. 67; 1996)

Melphalan [148-82-3] (Vol. 9, Suppl. 7; 1987)

8-Methoxypsoralen (Methoxsalen) [298-81-7] plus ultraviolet A radiation (Vol. 24, Suppl. 7; 1987)

MOPP and other combined chemotherapy including alkylating agents (Suppl. 7; 1987)

Mustard gas (Sulphur mustard) [505-60-2] (Vol. 9, Suppl. 7; 1987)

2-Naphthylamine [91-59-8] (Vol. 4, Suppl. 7; 1987)

Neutrons (Vol. 75; 2000)

Nickel compounds (Vol. 49; 1990)

(NB: Evaluated as a group)

Oestrogen therapy, postmenopausal (Vol. 72; 1999)

Oestrogens, nonsteroidal (Suppl. 7; 1987)

(NB: This evaluation applies to the group of compounds as a whole and not necessarily to all individual compounds within the group)

Oestrogens, steroidal (Suppl. 7; 1987)

(NB: This evaluation applies to the group of compounds as a whole and not necessarily to all individual compounds within the group)

*Opisthorchis viverrini* (infection with) (Vol. 61; 1994)

Oral contraceptives, combined (Vol. 72; 1999)

(NB: There is also conclusive evidence that these agents have a protective effect against cancers of the ovary and endometrium)

Oral contraceptives, sequential (Suppl. 7; 1987)

**Table 5.17 Cont'd**

Radon [10043-92-2] and its decay products (Vol. 43; 1988)  
 Schistosoma haematobium (infection with) (Vol. 61; 1994)  
 Silica [14808-60-7], crystalline (inhaled in the form of quartz or cristobalite from occupational sources) (Vol. 68; 1997)  
 Solar radiation (Vol. 55; 1992)  
 Talc containing asbestiform fibres (Vol. 42, Suppl. 7; 1987)  
 Tamoxifen [10540-29-1] (Vol. 66; 1996)  
 (NB: There is also conclusive evidence that this agent (tamoxifen) reduces the risk of contralateral breast cancer)  
 2,3,7,8-Tetrachlorodibenzo-para-dioxin [1746-01-6] (Vol. 69; 1997)  
 (NB: Overall evaluation upgraded from 2A to 1 with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Thiotepa [52-24-4] (Vol. 50; 1990)  
 Treosulfan [299-75-2] (Vol. 26, Suppl. 7; 1987)  
 Vinyl chloride [75-01-4] (Vol. 19, Suppl. 7; 1987)  
 X- and Gamma (g)-Radiation (Vol. 75; 2000)

#### *Mixtures*

Alcoholic beverages (Vol. 44; 1988)  
 Analgesic mixtures containing phenacetin (Suppl. 7; 1987)  
 Betel quid with tobacco (Vol. 37, Suppl. 7; 1987)  
 Coal-tar pitches [65996-93-2] (Vol. 35, Suppl. 7; 1987)  
 Coal-tars [8007-45-2] (Vol. 35, Suppl. 7; 1987)  
 Mineral oils, untreated and mildly treated (Vol. 33, Suppl. 7; 1987)  
 Salted fish (Chinese-style) (Vol. 56; 1993)  
 Shale-oils [68308-34-9] (Vol. 35, Suppl. 7; 1987)  
 Soots (Vol. 35, Suppl. 7; 1987)  
 Tobacco products, smokeless (Vol. 37, Suppl. 7; 1987)  
 Tobacco smoke (Vol. 38, Suppl. 7; 1987)  
 Wood dust (Vol. 62; 1995)

#### *Exposure circumstances*

Aluminium production (Vol. 34, Suppl. 7; 1987)  
 Auramine, manufacture of (Suppl. 7; 1987)  
 Boot and shoe manufacture and repair (Vol. 25, Suppl. 7; 1987)  
 Coal gasification (Vol. 34, Suppl. 7; 1987)  
 Coke production (Vol. 34, Suppl. 7; 1987)  
 Furniture and cabinet making (Vol. 25, Suppl. 7; 1987)  
 Haematite mining (underground) with exposure to radon (Vol. 1, Suppl. 7; 1987)  
 Iron and steel founding (Vol. 34, Suppl. 7; 1987)  
 Isopropanol manufacture (strong-acid process) (Suppl. 7; 1987)  
 Magenta, manufacture of (Vol. 57; 1993)  
 Painter (occupational exposure as a) (Vol. 47; 1989)  
 Rubber industry (Vol. 28, Suppl. 7; 1987)  
 Strong-inorganic-acid mists containing sulphuric acid (occupational exposure to) (Vol. 54; 1992)

### **Group 2A: Probably carcinogenic to humans (63)**

#### *Agents and groups of agents*

Acrylamide [79-06-1] (Vol. 60; 1994)  
 (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Adriamycin [23214-92-8] (Vol. 10, Suppl. 7; 1987)  
 (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Androgenic (anabolic) steroids (Suppl. 7; 1987)  
 Azacitidine [320-67-2] (Vol. 50; 1990)  
 (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Benz[a]anthracene [56-55-3] (Vol. 32, Suppl. 7; 1987)  
 (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Benzidine-based dyes (Suppl. 7; 1987)



Table 5.17 Cont'd

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|                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Benzo[a]pyrene [50-32-8] (Vol. 32, Suppl. 7; 1987)                                                                                                                                                |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Bischloroethyl nitrosourea (BCNU) [154-93-8] (Vol. 26, Suppl. 7; 1987)                                                                                                                            |
| 1,3-Butadiene [106-99-0] (Vol. 71; 1999)                                                                                                                                                          |
| Captafol [2425-06-1] (Vol. 53; 1991)                                                                                                                                                              |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Chloramphenicol [56-75-7] (Vol. 50; 1990)                                                                                                                                                         |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| a-Chlorinated toluenes (benzal chloride [98-87-3], benzotrichloride [98-07-7], benzyl chloride [100-44-7]) and benzoyl chloride [98-88-4] (combined exposures) (Vol. 29, Suppl. 7, Vol. 71; 1999) |
| 1-(2-Chloroethyl)-3-cyclohexyl-1-nitrosourea (CCNU) [13010-47-4] (Vol. 26, Suppl. 7; 1987)                                                                                                        |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| para-Chloro-ortho-toluidine [95-69-2] and its strong acid salts (Vol. 48, Vol. 77; 2000)                                                                                                          |
| (NB: Evaluated as a group)                                                                                                                                                                        |
| Chlorozotocin [54749-90-5] (Vol. 50; 1990)                                                                                                                                                        |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Cisplatin [15663-27-1] (Vol. 26, Suppl. 7; 1987)                                                                                                                                                  |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Clonorchis sinensis (infection with) (Vol. 61; 1994)                                                                                                                                              |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Dibenz[a,h]anthracene [53-70-3] (Vol. 32, Suppl. 7; 1987)                                                                                                                                         |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Diethyl sulphate [64-67-5] (Vol. 54, Vol. 71; 1999)                                                                                                                                               |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Dimethylcarbamoyl chloride [79-44-7] (Vol. 12, Suppl. 7, Vol. 71; 1999)                                                                                                                           |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| 1,2-Dimethylhydrazine [540-73-8] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                                                                |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Dimethyl sulphate [77-78-1] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                                                                     |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Epichlorohydrin [106-89-8] (Vol. 11, Suppl. 7, Vol. 71; 1999)                                                                                                                                     |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Ethylene dibromide [106-93-4] (Vol. 15, Suppl. 7, Vol. 71; 1999)                                                                                                                                  |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| N-Ethyl-N-nitrosourea [759-73-9] (Vol. 17, Suppl. 7; 1987)                                                                                                                                        |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)                                         |
| Etoposide [33419-42-0] (Vol. 76; 2000)                                                                                                                                                            |
| (NB: Other relevant data taken into consideration in making the overall evaluation)                                                                                                               |
| Formaldehyde [50-00-0] (Vol. 62; 1995)                                                                                                                                                            |
| Glycidol [556-52-5] (Vol. 77; 2000)                                                                                                                                                               |
| (NB: Other relevant data taken into consideration in making the overall evaluation)                                                                                                               |
| Human papillomavirus type 31 (Vol. 64; 1995)                                                                                                                                                      |
| Human papillomavirus type 33 (Vol. 64; 1995)                                                                                                                                                      |

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**Table 5.17 Cont'd**


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|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| IQ (2-Amino-3-methylimidazo[4,5-f]quinoline) [76180-96-6] (Vol. 56; 1993)                                                                                 |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Kaposi's sarcoma herpesvirus/human herpesvirus 8 (Vol. 70; 1997)                                                                                          |
| 5-Methoxypsoralen [484-20-8] (Vol. 40, Suppl. 7; 1987)                                                                                                    |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| 4,4'-Methylene bis(2-chloroaniline) (MbOCA) [101-14-4] (Vol. 57; 1993)                                                                                    |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Methyl methanesulphonate [66-27-3] (Vol. 7, Suppl. 7, Vol. 71; 1999)                                                                                      |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| N-Methyl-N'-nitro-N-nitrosoguanidine (MNNG) [70-25-7] (Vol. 4, Suppl. 7; 1987)                                                                            |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| N-Methyl-N-nitrosourea [684-93-5] (Vol. 17, Suppl. 7; 1987)                                                                                               |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Nitrogen mustard [51-75-2] (Vol. 9, Suppl. 7; 1987)                                                                                                       |
| N-Nitrosodiethylamine [55-18-5] (Vol. 17, Suppl. 7; 1987)                                                                                                 |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| N-Nitrosodimethylamine [62-75-9] (Vol. 17, Suppl. 7; 1987)                                                                                                |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Phenacetin [62-44-2] (Vol. 24, Suppl. 7; 1987)                                                                                                            |
| Procarbazine hydrochloride [366-70-1] (Vol. 26, Suppl. 7; 1987)                                                                                           |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Styrene-7,8-oxide [96-09-3] (Vol. 60; 1994)                                                                                                               |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Teniposide [29767-20-2] (Vol. 76; 2000)                                                                                                                   |
| (NB: Other relevant data taken into consideration in making the overall evaluation)                                                                       |
| Tetrachloroethylene [127-18-4] (Vol. 63; 1995)                                                                                                            |
| ortho-Toluidine [95-53-4] (Vol. 27, Suppl. 7, Vol. 77; 2000)                                                                                              |
| Trichloroethylene [79-01-6] (Vol. 63; 1995)                                                                                                               |
| 1,2,3-Trichloropropane [96-18-4] (Vol. 63; 1995)                                                                                                          |
| Tris(2,3-dibromopropyl) phosphate [126-72-7] (Vol. 20, Suppl. 7, Vol. 71; 1999)                                                                           |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Ultraviolet radiation A (Vol. 55; 1992)                                                                                                                   |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Ultraviolet radiation B (Vol. 55; 1992)                                                                                                                   |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Ultraviolet radiation C (Vol. 55; 1992)                                                                                                                   |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Vinyl bromide [593-60-2] (Vol. 39, Suppl. 7, Vol. 71; 1999)                                                                                               |
| (NB: Overall evaluation upgraded from 2B to 2A with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Vinyl fluoride [75-02-5] (Vol. 63; 1995)                                                                                                                  |

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*Mixtures*

Creosotes [8001-58-9] (Vol. 35, Suppl. 7; 1987)

Diesel engine exhaust (Vol. 46; 1989)

Hot mate (Vol. 51; 1991)

**Table 5.17 Cont'd**

Non-arsenical insecticides (occupational exposures in spraying and application of) (Vol. 53; 1991)  
 Polychlorinated biphenyls [1336-36-3] (Vol. 18, Suppl. 7; 1987)

*Exposure circumstances*

Art glass, glass containers and pressed ware (manufacture of) (Vol. 58; 1993)  
 Hairdresser or barber (occupational exposure as a) (Vol. 57; 1993)  
 Petroleum refining (occupational exposures in) (Vol. 45; 1989)  
 Sunlamps and sunbeds (use of) (Vol. 55; 1992)

**Group 2B: Possibly carcinogenic to humans (235)**

*Agents and groups of agents*

A-a-C (2-Amino-9H-pyrido[2,3-b]indole) [26148-68-5] (Vol. 40, Suppl. 7; 1987)  
 Acetaldehyde [75-07-0] (Vol. 36, Suppl. 7, Vol. 71; 1999)  
 Acetamide [60-35-5] (Vol. 7, Suppl. 7, Vol. 71; 1999)  
 Acrylonitrile [107-13-1] (Vol. 71; 1999)  
 AF-2 [2-(2-Furyl)-3-(5-nitro-2-furyl)acrylamide] [3688-53-7] (Vol. 31, Suppl. 7; 1987)  
 Aflatoxin M1 [6795-23-9] (Vol. 56; 1993)  
 para-Aminoazobenzene [60-09-3] (Vol. 8, Suppl. 7; 1987)  
 ortho-Aminoazotoluene [97-56-3] (Vol. 8, Suppl. 7; 1987)  
 2-Amino-5-(5-nitro-2-furyl)-1,3,4-thiadiazole [712-68-5] (Vol. 7, Suppl. 7; 1987)  
 Amitrole [61-82-5] (Vol. 41, Suppl. 7; 1987)  
 Amsacrine [51264-14-3] (Vol. 76; 2000)  
 ortho-Anisidine [90-04-0] (Vol. 73; 1999)  
 Antimony trioxide [1309-64-4] (Vol. 47; 1989)  
 Aramite® [140-57-8] (Vol. 5, Suppl. 7; 1987)  
 Auramine [492-80-8] (technical-grade) (Vol. 1, Suppl. 7; 1987)  
 Azaserine [115-02-6] (Vol. 10, Suppl. 7; 1987)  
 Aziridine [151-56-4] (Vol. 9, Suppl. 7, Vol. 71; 1999)  
 (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Benzo[b]fluoranthene [205-99-2] (Vol. 32, Suppl. 7; 1987)  
 Benzo[j]fluoranthene [205-82-3] (Vol. 32, Suppl. 7; 1987)  
 Benzo[k]fluoranthene [207-08-9] (Vol. 32, Suppl. 7; 1987)  
 Benzofuran [271-89-6] (Vol. 63; 1995)  
 Benzyl violet 4B [1694-09-3] (Vol. 16, Suppl. 7; 1987)  
 2,2-Bis(bromomethyl)propane-1,3-diol [3296-90-0] (Vol. 77; 2000)  
 Bleomycins [11056-06-7] (Vol. 26, Suppl. 7; 1987)  
 (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Bracken fern (Vol. 40, Suppl. 7; 1987)  
 Bromodichloromethane [75-27-4] (Vol. 52, Vol. 71; 1999)  
 Butylated hydroxyanisole (BHA) [25013-16-5] (Vol. 40, Suppl. 7; 1987)  
 b-Butyrolactone [3068-88-0] (Vol. 11, Suppl. 7, Vol. 71; 1999)  
 Caffeic acid [331-39-5] (Vol. 56; 1993)  
 Carbon black [1333-86-4] (Vol. 65; 1996)  
 Carbon tetrachloride [56-23-5] (Vol. 20, Suppl. 7, Vol. 71; 1999)  
 Catechol [120-80-9] (Vol. 15, Suppl. 7, Vol. 71; 1999)  
 Ceramic fibres (Vol. 43; 1988)  
 Chlordane [57-74-9] (Vol. 53; 1991)  
 Chlordecone (Kepone) [143-50-0] (Vol. 20, Suppl. 7; 1987)  
 Chlorendic acid [115-28-6] (Vol. 48; 1990)  
 para-Chloroaniline [106-47-8] (Vol. 57; 1993)  
 Chloroform [67-66-3] (Vol. 73; 1999)  
 1-Chloro-2-methylpropene [513-37-1] (Vol. 63; 1995)  
 Chlorophenoxy herbicides (Vol. 41, Suppl. 7; 1987)  
 4-Chloro-ortho-phenylenediamine [95-83-0] (Vol. 27, Suppl. 7; 1987)  
 Chloroprene [126-99-8] (Vol. 71; 1999)  
 Chlorothalonil [1897-45-6] (Vol. 73; 1999)  
 CI Acid Red 114 [6459-94-5] (Vol. 57; 1993)

**Table 5.17 Cont'd**


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| CI Basic Red 9 [569-61-9] (Vol. 57; 1993)                                                                                                                |
| CI Direct Blue 15 [2429-74-5] (Vol. 57; 1993)                                                                                                            |
| Citrus Red No. 2 [6358-53-8] (Vol. 8, Suppl. 7; 1987)                                                                                                    |
| Cobalt [7440-48-4] and cobalt compounds (Vol. 52; 1991)                                                                                                  |
| (NB: Evaluated as a group)                                                                                                                               |
| para-Cresidine [120-71-8] (Vol. 27, Suppl. 7; 1987)                                                                                                      |
| Cycasin [14901-08-7] (Vol. 10, Suppl. 7; 1987)                                                                                                           |
| Dacarbazine [4342-03-4] (Vol. 26, Suppl. 7; 1987)                                                                                                        |
| Dantron (Chrysazin; 1,8-Dihydroxyanthraquinone) [117-10-2] (Vol. 50; 1990)                                                                               |
| Daunomycin [20830-81-3] (Vol. 10, Suppl. 7; 1987)                                                                                                        |
| DDT [ <i>p,p'</i> -DDT, 50-29-3] (Vol. 53; 1991)                                                                                                         |
| <i>N,N'</i> -Diacetylbenzidine [613-35-4] (Vol. 16, Suppl. 7; 1987)                                                                                      |
| 2,4-Diaminoanisole [615-05-4] (Vol. 27, Suppl. 7; 1987)                                                                                                  |
| 4,4'-Diaminodiphenyl ether [101-80-4] (Vol. 29, Suppl. 7; 1987)                                                                                          |
| 2,4-Diaminotoluene [95-80-7] (Vol. 16, Suppl. 7; 1987)                                                                                                   |
| Dibenz[ <i>a,h</i> ]acridine [226-36-8] (Vol. 32, Suppl. 7; 1987)                                                                                        |
| Dibenz[ <i>a,j</i> ]acridine [224-42-0] (Vol. 32, Suppl. 7; 1987)                                                                                        |
| 7H-Dibenzo[ <i>c,g</i> ]carbazole [194-59-2] (Vol. 32, Suppl. 7; 1987)                                                                                   |
| Dibenzo[ <i>a,e</i> ]pyrene [192-65-4] (Vol. 32, Suppl. 7; 1987)                                                                                         |
| Dibenzo[ <i>a,h</i> ]pyrene [189-64-0] (Vol. 32, Suppl. 7; 1987)                                                                                         |
| Dibenzo[ <i>a,i</i> ]pyrene [189-55-9] (Vol. 32, Suppl. 7; 1987)                                                                                         |
| Dibenzo[ <i>a,l</i> ]pyrene [191-30-0] (Vol. 32, Suppl. 7; 1987)                                                                                         |
| 1,2-Dibromo-3-chloropropane [96-12-8] (Vol. 20, Suppl. 7, Vol. 71; 1999)                                                                                 |
| 2,3-Dibromopropan-1-ol [96-13-9] (Vol. 77; 2000)                                                                                                         |
| para-Dichlorobenzene [106-46-7] (Vol. 73; 1999)                                                                                                          |
| 3,3'-Dichlorobenzidine [91-94-1] (Vol. 29, Suppl. 7; 1987)                                                                                               |
| 3,3'-Dichloro-4,4'-diaminodiphenyl ether [28434-86-8] (Vol. 16, Suppl. 7; 1987)                                                                          |
| 1,2-Dichloroethane [107-06-2] (Vol. 20, Suppl. 7, Vol. 71; 1999)                                                                                         |
| Dichloromethane (methylene chloride) [75-09-2] (Vol. 71; 1999)                                                                                           |
| 1,3-Dichloropropene [542-75-6] (technical-grade) (Vol. 41, Suppl. 7, Vol. 71; 1999)                                                                      |
| Dichlorvos [62-73-7] (Vol. 53; 1991)                                                                                                                     |
| 1,2-Diethylhydrazine [1615-80-1] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                       |
| Diglycidyl resorcinol ether [101-90-6] (Vol. 36, Suppl. 7, Vol. 71; 1999)                                                                                |
| Dihydrosafrole [94-58-6] (Vol. 10, Suppl. 7; 1987)                                                                                                       |
| Diisopropyl sulphate [2973-10-6] (Vol. 54, Vol. 71; 1999)                                                                                                |
| 3,3'-Dimethoxybenzidine (ortho-Dianisidine) [119-90-4] (Vol. 4, Suppl. 7; 1987)                                                                          |
| para-Dimethylaminoazobenzene [60-11-7] (Vol. 8, Suppl. 7; 1987)                                                                                          |
| trans-2-[(Dimethylamino)methylimino]-5-[2-(5-nitro-2-furyl)-vinyl]-1,3,4-oxadiazole [25962-77-0] (Vol. 7, Suppl. 7; 1987)                                |
| 2,6-Dimethylaniline (2,6-Xylidine) [87-62-7] (Vol. 57; 1993)                                                                                             |
| 3,3'-Dimethylbenzidine (ortho-Tolidine) [119-93-7] (Vol. 1, Suppl. 7; 1987)                                                                              |
| 1,1-Dimethylhydrazine [57-14-7] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                        |
| 3,7-Dinitrofluoranthene [105735-71-5] (Vol. 65; 1996)                                                                                                    |
| 3,9-Dinitrofluoranthene [22506-53-2] (Vol. 65; 1996)                                                                                                     |
| 1,6-Dinitropyrene [42397-64-8] (Vol. 46; 1989)                                                                                                           |
| 1,8-Dinitropyrene [42397-65-9] (Vol. 46; 1989)                                                                                                           |
| 2,4-Dinitrotoluene [121-14-2] (Vol. 65; 1996)                                                                                                            |
| 2,6-Dinitrotoluene [606-20-2] (Vol. 65; 1996)                                                                                                            |
| 1,4-Dioxane [123-91-1] (Vol. 11, Suppl. 7, Vol. 71; 1999)                                                                                                |
| Disperse Blue 1 [2475-45-8] (Vol. 48; 1990)                                                                                                              |
| 1,2-Epoxybutane [106-88-7] (Vol. 47, Vol. 71; 1999)                                                                                                      |
| (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Ethyl acrylate [140-88-5] (Vol. 39, Suppl. 7, Vol. 71; 1999)                                                                                             |
| Ethylbenzene [100-41-4] (Vol. 77; 2000)                                                                                                                  |
| Ethylene thiourea [96-45-7] (Vol. 7, Suppl. 7; 1987)                                                                                                     |
| Ethyl methanesulfonate [62-50-0] (Vol. 7, Suppl. 7; 1987)                                                                                                |
| Foreign bodies, implanted in tissues (Vol. 74; 1999)                                                                                                     |
| Polymeric, prepared as thin smooth films (with the exception of poly(glycolic acid))                                                                     |
| Metallic, prepared as thin smooth films                                                                                                                  |
| Metallic cobalt, metallic nickel and an alloy powder containing 66–67% nickel, 13–16% chromium and 7% iron                                               |

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Table 5.17 Cont'd

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| 2-(2-Formylhydrazino)-4-(5-nitro-2-furyl)thiazole [3570-75-0] (Vol. 7, Suppl. 7; 1987)                    |
| Furan [110-00-9] (Vol. 63; 1995)                                                                          |
| Glasswool (Vol. 43; 1988)                                                                                 |
| Glu-P-1 (2-Amino-6-methyldipyrido[1,2-a:3',2'-d]imidazole) [67730-11-4] (Vol. 40, Suppl. 7; 1987)         |
| Glu-P-2 (2-Aminodipyrido[1,2-a:3',2'-d]imidazole) [67730-10-3] (Vol. 40, Suppl. 7; 1987)                  |
| Glycidaldehyde [765-34-4] (Vol. 11, Suppl. 7, Vol. 71; 1999)                                              |
| Griseofulvin [126-07-8] (Vol. 10, Suppl. 7; 1987)                                                         |
| HC Blue No. 1 [2784-94-3] (Vol. 57; 1993)                                                                 |
| Heptachlor [76-44-8] (Vol. 53; 1991)                                                                      |
| Hexachlorobenzene [118-74-1] (Vol. 20, Suppl. 7; 1987)                                                    |
| Hexachloroethane [67-72-1] (Vol. 73; 1999)                                                                |
| Hexachlorocyclohexanes (Vol. 20, Suppl. 7; 1987)                                                          |
| Hexamethylphosphoramide [680-31-9] (Vol. 15, Suppl. 7, Vol. 71; 1999)                                     |
| Human immunodeficiency virus type 2 (infection with) (Vol. 67; 1996)                                      |
| Human papillomaviruses: some types other than 16, 18, 31 and 33 (Vol. 64; 1995)                           |
| Hydrazine [302-01-2] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                    |
| Indeno[1,2,3-cd]pyrene [193-39-5] (Vol. 32, Suppl. 7; 1987)                                               |
| Iron-dextran complex [9004-66-4] (Vol. 2, Suppl. 7; 1987)                                                 |
| Isoprene [78-79-5] (Vol. 60, Vol. 71; 1999)                                                               |
| Lasiocarpine [303-34-4] (Vol. 10, Suppl. 7; 1987)                                                         |
| Lead [7439-92-1] and lead compounds, inorganic (Vol. 23, Suppl. 7; 1987)                                  |
| (NB: Evaluated as a group)                                                                                |
| Magenta [632-99-5] (containing CI Basic Red 9) (Vol. 57; 1993)                                            |
| MeA-a-C (2-Amino-3-methyl-9H-pyrido[2,3-b]indole) [68006-83-7] (Vol. 40, Suppl. 7; 1987)                  |
| Medroxyprogesterone acetate [71-58-9] (Vol. 21, Suppl. 7; 1987)                                           |
| MeIQ (2-Amino-3,4-dimethylimidazo[4,5-f]quinoline) [77094-11-2] (Vol. 56; 1993)                           |
| MeIQx (2-Amino-3,8-dimethylimidazo[4,5-f]quinoxaline) [77500-04-0] (Vol. 56; 1993)                        |
| Merphalan [531-76-0] (Vol. 9, Suppl. 7; 1987)                                                             |
| 2-Methylaziridine (Propyleneimine) [75-55-8] (Vol. 9, Suppl. 7, Vol. 71; 1999)                            |
| Methylazoxymethanol acetate [592-62-1] (Vol. 10, Suppl. 7; 1987)                                          |
| 5-Methylchrysene [3697-24-3] (Vol. 32, Suppl. 7; 1987)                                                    |
| 4,4'-Methylene bis(2-methylaniline) [838-88-0] (Vol. 4, Suppl. 7; 1987)                                   |
| 4,4'-Methylenedianiline [101-77-9] (Vol. 39, Suppl. 7; 1987)                                              |
| Methylmercury compounds (Vol. 58; 1993)                                                                   |
| (NB: Evaluated as a group)                                                                                |
| 2-Methyl-1-nitroanthraquinone [129-15-7] (uncertain purity) (Vol. 27, Suppl. 7; 1987)                     |
| N-Methyl-N-nitrosourethane [615-53-2] (Vol. 4, Suppl. 7; 1987)                                            |
| Methylthiouracil [56-04-2] (Vol. 7, Suppl. 7; 1987)                                                       |
| Metronidazole [443-48-1] (Vol. 13, Suppl. 7; 1987)                                                        |
| Mirex [2385-85-5] (Vol. 20, Suppl. 7; 1987)                                                               |
| Mitomycin C [50-07-7] (Vol. 10, Suppl. 7; 1987)                                                           |
| Mitoxantrone [65271-80-9] (Vol. 76; 2000)                                                                 |
| Monocrotaline [315-22-0] (Vol. 10, Suppl. 7; 1987)                                                        |
| 5-(Morpholinomethyl)-3-[(5-nitrofurfurylidene)amino]-2-oxazolidinone [3795-88-8] (Vol. 7, Suppl. 7; 1987) |
| Nafenopin [3771-19-5] (Vol. 24, Suppl. 7; 1987)                                                           |
| Nickel, metallic [7440-02-0] and alloys (Vol. 49; 1990)                                                   |
| Niridazole [61-57-4] (Vol. 13, Suppl. 7; 1987)                                                            |
| Nitrilotriacetic acid [139-13-9] and its salts (Vol. 73; 1999)                                            |
| (NB: Evaluated as a group)                                                                                |
| 5-Nitroacenaphthene [602-87-9] (Vol. 16, Suppl. 7; 1987)                                                  |
| 2-Nitroanisole [91-23-6] (Vol. 65; 1996)                                                                  |
| Nitrobenzene [98-95-3] (Vol. 65; 1996)                                                                    |
| 6-Nitrochrysene [7496-02-8] (Vol. 46; 1989)                                                               |
| Nitrofen [1836-75-5] (technical-grade) (Vol. 30, Suppl. 7; 1987)                                          |
| 2-Nitrofluorene [607-57-8] (Vol. 46; 1989)                                                                |
| 1-[(5-Nitrofurfurylidene)amino]-2-imidazolidinone [555-84-0] (Vol. 7, Suppl. 7; 1987)                     |
| N-[4-(5-Nitro-2-furyl)-2-thiazolyl]acetamide [531-82-8] (Vol. 7, Suppl. 7; 1987)                          |
| Nitrogen mustard N-oxide [126-85-2] (Vol. 9, Suppl. 7; 1987)                                              |
| Nitromethane [75-52-5] (Vol. 77; 2000)                                                                    |
| 2-Nitropropane [79-46-9] (Vol. 29, Suppl. 7, Vol. 71; 1999)                                               |

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**Table 5.17 Cont'd**


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| 1-Nitropyrene [5522-43-0] (Vol. 46; 1989)                                                                                                                |
| 4-Nitropyrene [57835-92-4] (Vol. 46; 1989)                                                                                                               |
| N-Nitrosodi- <i>n</i> -butylamine [924-16-3] (Vol. 17, Suppl. 7; 1987)                                                                                   |
| N-Nitrosodiethanolamine [1116-54-7] (Vol. 17, Suppl. 7, Vol. 77; 2000)                                                                                   |
| N-Nitrosodi- <i>n</i> -propylamine [621-64-7] (Vol. 17, Suppl. 7; 1987)                                                                                  |
| 3-(N-Nitrosomethylamino)propionitrile [60153-49-3] (Vol. 37, Suppl. 7; 1987)                                                                             |
| 4-(N-Nitrosomethylamino)-1-(3-pyridyl)-1-butanone (NNK) [64091-91-4] (Vol. 37, Suppl. 7; 1987)                                                           |
| N-Nitrosomethylethylamine [10595-95-6] (Vol. 17, Suppl. 7; 1987)                                                                                         |
| N-Nitrosomethylvinylamine [4549-40-0] (Vol. 17, Suppl. 7; 1987)                                                                                          |
| N-Nitrosomorpholine [59-89-2] (Vol. 17, Suppl. 7; 1987)                                                                                                  |
| N <sup>o</sup> -Nitrosomorpholine [16543-55-8] (Vol. 37, Suppl. 7; 1987)                                                                                 |
| N-Nitrosopiperidine [100-75-4] (Vol. 17, Suppl. 7; 1987)                                                                                                 |
| N-Nitrosopyrrolidine [930-55-2] (Vol. 17, Suppl. 7; 1987)                                                                                                |
| N-Nitrososarcosine [13256-22-9] (Vol. 17, Suppl. 7; 1987)                                                                                                |
| Ochratoxin A [303-47-9] (Vol. 56; 1993)                                                                                                                  |
| Oestrogen–progestogen therapy, postmenopausal (Vol. 72; 1999)                                                                                            |
| Oil Orange SS [2646-17-5] (Vol. 8, Suppl. 7; 1987)                                                                                                       |
| Oxazepam [604-75-1] (Vol. 66; 1996)                                                                                                                      |
| Palygorskite (attapulgite) [12174-11-7] (long fibres, >5 micrometres) (Vol. 68; 1997)                                                                    |
| Panfuran S [794-93-4] (containing dihydroxymethylfurazirine)<br>(Vol. 24, Suppl. 7; 1987)                                                                |
| Phenazopyridine hydrochloride [136-40-3] (Vol. 24, Suppl. 7; 1987)                                                                                       |
| Phenobarbital [50-06-6] (Vol. 13, Suppl. 7; 1987)                                                                                                        |
| Phenolphthalein [77-09-8] (Vol. 76; 2000)                                                                                                                |
| Phenoxybenzamine hydrochloride [63-92-3] (Vol. 24, Suppl. 7; 1987)                                                                                       |
| Phenyl glycidyl ether [122-60-1] (Vol. 47, Vol. 71; 1999)                                                                                                |
| Phenytoin [57-41-0] (Vol. 66; 1996)                                                                                                                      |
| PhIP (2-Amino-1-methyl-6-phenylimidazo[4,5- <i>b</i> ]pyridine) [105650-23-5] (Vol. 56; 1993)                                                            |
| Polychlorophenols and their sodium salts (mixed exposures) (Vol. 41, Suppl. 7, Vol. 53, Vol. 71; 1999)                                                   |
| Ponceau MX [3761-53-3] (Vol. 8, Suppl. 7; 1987)                                                                                                          |
| Ponceau 3R [3564-09-8] (Vol. 8, Suppl. 7; 1987)                                                                                                          |
| Potassium bromate [7758-01-2] (Vol. 73; 1999)                                                                                                            |
| Progestins (Suppl. 7; 1987)                                                                                                                              |
| Progestogen-only contraceptives (Vol. 72; 1999)                                                                                                          |
| 1,3-Propane sultone [1120-71-4] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                        |
| b-Propiolactone [57-57-8] (Vol. 4, Suppl. 7, Vol. 71; 1999)                                                                                              |
| Propylene oxide [75-56-9] (Vol. 60; 1994)                                                                                                                |
| Propylthiouracil [51-52-5] (Vol. 7, Suppl. 7; 1987)                                                                                                      |
| Rockwool (Vol. 43; 1988)                                                                                                                                 |
| Safole [94-59-7] (Vol. 10, Suppl. 7; 1987)                                                                                                               |
| Schistosoma japonicum (infection with) (Vol. 61; 1994)                                                                                                   |
| Slagwool (Vol. 43; 1988)                                                                                                                                 |
| Sodium ortho-phenylphenate [132-27-4] (Vol. 73; 1999)                                                                                                    |
| Sterigmatocystin [10048-13-2] (Vol. 10, Suppl. 7; 1987)                                                                                                  |
| Streptozotocin [18883-66-4] (Vol. 17, Suppl. 7; 1987)                                                                                                    |
| Styrene [100-42-5] (Vol. 60; 1994)                                                                                                                       |
| (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms) |
| Sulfallate [95-06-7] (Vol. 30, Suppl. 7; 1987)                                                                                                           |
| Tetrafluoroethylene [116-14-3] (Vol. 19, Suppl. 7, Vol. 71; 1999)                                                                                        |
| Tetranitromethane [509-14-8] (Vol. 65; 1996)                                                                                                             |
| Thioacetamide [62-55-5] (Vol. 7, Suppl. 7; 1987)                                                                                                         |
| 4,4'-Thiodianiline [139-65-1] (Vol. 27, Suppl. 7; 1987)                                                                                                  |
| Thiourea [62-56-6] (Vol. 7, Suppl. 7; 1987)                                                                                                              |
| Toluene diisocyanates [26471-62-5] (Vol. 39, Suppl. 7, Vol. 71; 1999)                                                                                    |
| Toxins derived from <i>Fusarium moniliforme</i> (Vol. 56; 1993)                                                                                          |
| Trichlormethine (Trimustine hydrochloride) [817-09-4] (Vol. 50; 1990)                                                                                    |
| Trp-P-1 (3-Amino-1,4-dimethyl-5H-pyrido[4,3- <i>b</i> ]indole) [62450-06-0] (Vol. 31, Suppl. 7; 1987)                                                    |
| Trp-P-2 (3-Amino-1-methyl-5H-pyrido[4,3- <i>b</i> ]indole) [62450-07-1] (Vol. 31, Suppl. 7; 1987)                                                        |
| Trypan blue [72-57-1] (Vol. 8, Suppl. 7; 1987)                                                                                                           |

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**Table 5.17 Cont'd**

Uracil mustard [66-75-1] (Vol. 9, Suppl. 7; 1987)  
 Urethane [51-79-6] (Vol. 7, Suppl. 7; 1987)  
 Vinyl acetate [108-05-4] (Vol. 63; 1995)  
 4-Vinylcyclohexene [100-40-3] (Vol. 60; 1994)  
 4-Vinylcyclohexene diepoxide [106-87-6] (Vol. 60; 1994)  
 Zalcitabine [7481-89-2] (Vol. 76; 2000)  
 Zidovudine (AZT) [30516-87-1] (Vol. 76; 2000)

*Mixtures*

Bitumens [8052-42-4], extracts of steam-refined and air-refined (Vol. 35, Suppl. 7; 1987)  
 Carrageenan [9000-07-1], degraded (Vol. 31, Suppl. 7; 1987)  
 Chlorinated paraffins of average carbon chain length C12 and average degree of chlorination approximately 60% (Vol. 48; 1990)  
 Coffee (urinary bladder) (Vol. 51; 1991)  
 (NB: There is some evidence of an inverse relationship between coffee drinking and cancer of the large bowel; coffee drinking could not be classified as to its carcinogenicity to other organs)  
 Diesel fuel, marine (Vol. 45; 1989)  
 (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Engine exhaust, gasoline (Vol. 46; 1989)  
 Fuel oils, residual (heavy) (Vol. 45; 1989)  
 Gasoline (Vol. 45; 1989)  
 (NB: Overall evaluation upgraded from 3 to 2B with supporting evidence from other data relevant to the evaluation of carcinogenicity and its mechanisms)  
 Pickled vegetables (traditional in Asia) (Vol. 56; 1993)  
 Polybrominated biphenyls [Firemaster BP-6, 59536-65-1] (Vol. 41, Suppl. 7; 1987)  
 Toxaphene (Polychlorinated camphenes) [8001-35-2] (Vol. 20, Suppl. 7; 1987)  
 Welding fumes (Vol. 49; 1990)

*Exposure circumstances*

Carpentry and joinery (Vol. 25, Suppl. 7; 1987)  
 Dry cleaning (occupational exposures in) (Vol. 63; 1995)  
 Printing processes (occupational exposures in) (Vol. 65; 1996)  
 Textile manufacturing industry (work in) (Vol. 48; 1990)

Identification by labels, numbers, colour coding etc. of vessels, transfer lines and valves.  
 Clear, unambiguous operating instructions (updated and freely available).  
 Segregated disposal of residues, 'empty' sacks, containers, liquid effluents, solid wastes, floor-washes etc.

***Control strategies in general***

Strategies for reducing the risk from a toxic chemical depends upon its nature (i.e. toxic, corrosive, dermatitic) and extent. A combination of the following measures may be appropriate.

*Substitution*

Hazardous chemicals or mixtures may be replaceable by safer materials. These may be less toxic *per se*, or less easily dispersed (e.g. less volatile or dusty). Substitution is also applicable to synthesis routes to avoid the use of toxic reactants/solvents or the production, either intentionally or accidentally, of toxic intermediates, by-products or wastes.

*Minimization of inventory*

As a general rule, it is preferable to minimize the amounts of toxic chemicals in storage and in process. There may be an advantage in handling chemicals in the most dilute practicable concentration.

**Table 5.18 Common sources of toxic atmospheres**

| <i>Source</i>                                                     | <i>Examples</i>                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Improper storage, handling, use or disposal of specific chemicals | Leakages <sup>(1)</sup><br>Improper venting or draining <sup>(1)</sup><br>Open handling <sup>(1)</sup><br>Incorrect notification on disposal<br>Use of wrong material                                                                                                                                                                      |
| Accidental release, spillage                                      | Transport incidents<br>Overfilling of containers<br>Equipment failure<br>Unexpected reactions<br>Runaway reactions                                                                                                                                                                                                                         |
| Admixture of chemicals                                            | By mistake, e.g. wrongly identified<br>In wrong proportions<br>In wrong circumstances <sup>(1)</sup><br>In wrong sequence                                                                                                                                                                                                                  |
| Fires                                                             | Pyrolysis products<br>Combustion products <sup>(1)</sup><br>Vaporization<br>Through domino effects                                                                                                                                                                                                                                         |
| Operation in confined spaces                                      | Improper isolation<br>From residues<br>Oxygen deficiency (inherent, from purging or from rusting)                                                                                                                                                                                                                                          |
| Maintenance or cleaning of equipment                              | Residues<br>Loss of containment (breaking lines)<br>Stripping insulation<br>Burning-off paint, flame heating components<br>Reaction or vaporization of cleaning products                                                                                                                                                                   |
| Wastes                                                            | Anaerobic breakdown<br>Admixture of effluents<br>Open handling of effluents or 'wastes'<br>Atmospheric venting<br>Solid wastes<br>Uncontrolled incineration                                                                                                                                                                                |
| Fabrication, manufacturing or machining operations etc.           | Welding fumes <sup>(1)</sup><br>Spray painting, curing of paints <sup>(1)</sup><br>Use of adhesives, curing of adhesives <sup>(1)</sup><br>Cutting/grinding/fettling/shotblasting <sup>(1)</sup><br>Electroplating <sup>(1)</sup><br>Degreasing/cleaning/etching/pickling <sup>(1)</sup><br>Plastics forming or overheating <sup>(1)</sup> |

<sup>(1)</sup> May result in long-term exposure (throughout operation or in workplace).

### *Mechanical handling*

Release of, and exposure of personnel to, toxic chemicals can be reduced by appropriate mechanical handling and enclosed transfer, including:

In-plant transfer via pipelines.

In-plant transfer in specially designed containers, e.g. tote bins, corrosion-resistant containers, with provision for mechanical lifting.

Use of enclosed transfer by pressurization or vacuum, with appropriate balancing or venting,



(e.g. with knock-out and/or scrubbing, filtration or incineration for vapours/gases), or recovery (e.g. adsorption or vapour recompression) provisions.

Use of enclosed belt conveyors, chutes or pneumatic conveyors for solids.

Enclosed transfer of solids using screw feeders.

Transfer of solids in sealed containers or plastic sacks in preset batch weights, so avoiding emptying for reweighing.

Vessel or equipment cleaning can also be automated, e.g. using high-pressure liquid sprays. This is essential, whenever practicable, to avoid entry under the Confined Spaces Regulations 1997.

### *Process change*

A modification to the chemical process or manufacturing operation can reduce risk, for example:

Purification of raw materials.

Use of solutions, slurries, pellets, granules or 'dust-free' (i.e. partially-wetted) powders instead of dry powders.

Centralized make-up of toxic chemicals in master batches for transfer in sealed containers or impermeable bags.

Transfer of an active chemical agent in an inherently safer form (e.g. sulphur dioxide as sodium metabisulphite, chlorine as sodium hypochlorite). Generation of an active agent in this manner clearly reduces the inventory in use.

### *Suppression*

Release of liquids (as mists or sprays), of vapour or of dusts may be reduced in some cases by suppression methods. Such practices include:

Pre-wetting of powders or fibrous solids. This extends to wet sweeping (if vacuum cleaning is impractical).

Use of a cover on open-topped tanks, vats or portable containers when not in use, or other methods to reduce the exposed liquid surface.

Use of floating roof tanks.

Lowering the operating temperature of process liquids.

Provision of a partial seal on exposed liquid interfaces, e.g. a foam blanket or a layer of floating inert spheres.

Provision of a vapour recovery system on storage tanks.

### *Monitoring of equipment operation and of process parameters*

The use of appropriate instruments to monitor equipment operation and relevant process variables will detect, and provide warning of, undesirable excursions. Otherwise these can result in equipment failure or escape of chemicals, e.g. due to atmospheric venting, leakage or spillage. Instruments may facilitate automatic control, emergency action such as coolant or pressure relief or emergency shutdown, or the operation of water deluge systems.

Parameters which may be monitored include:

Electrical power drawn by prime movers.

Equipment vibration.

Coolant flow and temperatures (in and out); low flow and high temperature.  
Composition of process and effluent streams.  
Pressure or vacuum; high or low pressure.  
Process temperature; high or low temperature.  
Flow rates of process fluids; high or low flow.  
Pressure drop.  
Oxygen concentration.  
pH; high or low pH.  
Liquid (or particulate solid) level; high or low level.  
Atmospheric concentration of specific pollutants.

### *Segregation*

Segregation is a common means of controlling toxic risks, or restricting the working area exposed to them. Segregation may be by any, or a combination, of:

Distance, e.g. spacing of equipment, operating stations, storage, buildings.  
Physical barriers, e.g. splashguards, screens, or use of separate rooms. In special cases equipment enclosures and/or complete rooms may be maintained under a slight negative pressure.  
Time, e.g. performance of cleaning, demolition or stripping operations 'out-of-hours'. Rotation of jobs, and limitation of exposure, e.g. in confined spaces, are also examples of partial segregation.

### *Containment*

Contamination of the working environment can be prevented by complete containment, i.e. complete enclosure as in glove boxes in a laboratory or operation in sealed equipment. For materials transfer, balancing is preferred to venting. However, additional precautions are necessary for cleaning, emergency venting, sampling – foreseeable events which could result in unplanned leakage or spillage. Minimize pumping or blowing, sample points, pipe joints and equipment requiring maintenance, and avoid hoses unless reinforced and properly secured, e.g. armoured hose. Consider tank draining/recovery arrangements. Provide adequate instrumentation on storage tanks, e.g. temperature indicator, high temperature alarm, pressure indicator, high pressure alarm and level gauge, together with relief if necessary (safety valve backed up by rupture disk to prevent seepage). Provide bunds to contain spillages and protect drainage systems and sewers.

### *Local exhaust ventilation*

Because complete containment is physically impracticable in many cases, local exhaust ventilation is often applied to remove contaminants. The objective is to extract pollutant as near as practicable to its source and before it enters, or passes through, a worker's breathing zone. Vents should lead away from personnel to a safe location, with scrubbing/filtering as appropriate. Common examples are:

Laboratory fume cupboards, operated with the front sash at the correct setting and providing the requisite linear air velocity at the gap.  
Lip extraction at anticipated points of leakage (e.g. around open-topped tanks, sampling, drumming/packing points).  
Open-fronted extraction booths for spraying operations, or adhesive application operations.

Typical minimum transport velocities are given in Table 12.13 and capture velocities for various applications in Table 12.12.

General ventilation, which relies upon dilution by a combination of fresh air make-up and removal, is a secondary measure.

### *Personal protection*

The provision and use of properly selected personal protective equipment is normally regarded as back-up for the previous measures. Refer to Chapter 13. In some situations it is the only reasonably practicable measure to ensure personal safety and its use may be a legal requirement. Examples are:

- For entry into a confined space which may contain toxic chemicals or be oxygen deficient. Refer to Figure 13.1.

- During certain maintenance operations.

- During fire-fighting or emergency rescue operations.

- As a standby for emergency use in case of accidental release of toxic materials, e.g. during tanker unloading, or disconnection of temporary pipelines or when dealing with spillages generally, or if other protective measures, e.g. local exhaust ventilation, fail in service.

- As protection against chemicals to which no exposure is permissible or desirable.

### *Personal hygiene*

A good standard of personal hygiene is required to minimize exposure by ingestion or skin absorption of chemicals. The measures include:

- Adequate washing facilities with hot and cold running water, soap or hand cleanser, and drying provisions all conveniently located.

- Supply of an appropriate barrier cream (i.e. for 'wet' or 'dry' work) and afterwork cream.

- Adequate showering/bathing facilities.

- Avoidance of use of solvents, abrasive powders or process chemicals for skin cleaning.

- Provision of overalls of an appropriate type and their frequent laundering either in-house or by an approved contractor, with a prohibition on their unauthorized removal from the workplace or use in e.g. canteens. Disposable overalls are appropriate in some situations.

- Prompt attention to, and covering of, damaged or perforated areas of skin.

- Avoidance of eating, drinking, the application of cosmetics, or smoking in the work area.

Medical supervision and biological monitoring may be appropriate.

Training for all staff, covering both normal operation and emergency situations, is essential.

The combination of measures used will depend upon the degree of hazard, and the scale and nature of the processes. For example, dust and fume control measures in the rubber industry are summarized in Table 5.19.

## **Control of substances hazardous to health**

In Great Britain the COSHH Regulations cover virtually all substances hazardous to health. (Excluded are asbestos, lead, materials dangerous solely due to their radioactive, explosive, or flammable properties, or solely because of high or low temperatures or pressures, or where risk

**Table 5.19 Combination of measures for dust and fume control in the rubber industry**

| <i>Factory process</i>           | <i>Health hazard</i>                                | <i>Control measures</i>                                                                                                                   |
|----------------------------------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Drug room</b>                 | Dust from 'small drugs' (complex organic compounds) | Substitution<br>Master batches<br>Prewriteghed, sealed bags<br>Dust-suppressed chemicals<br>Local exhaust ventilation<br>Care in handling |
|                                  | Dust from bulk fillers and whittings                | Local exhaust ventilation<br>Care in handling                                                                                             |
|                                  | Dust from carbon black                              | Master batches<br>Local exhaust ventilation<br>Totally enclosed systems<br><i>Not</i> by 'careful handling' alone                         |
|                                  | Skin contact with process oils                      | Direct metering into mixer<br>Care in handling and protective clothing.                                                                   |
| <b>Compounding</b>               | Dust                                                | Local exhaust ventilation<br>Master batches<br>Prewriteghed, sealed bags<br>Dust-suppressed chemicals<br>Care in handling                 |
|                                  | Fume                                                | Local exhaust ventilation<br>Removal of hot product from workroom – cool before handling                                                  |
|                                  | Skin contact with process oils                      | Direct metering<br>Care in handling and protective clothing                                                                               |
| <b>Moulding</b>                  | Fume                                                | Local exhaust ventilation<br>Removal of hot product from workroom – cool before handling<br>Deflection by shields                         |
| <b>Calendering and extruding</b> | Fume                                                | Local exhaust ventilation<br>Water cooling of extrudate                                                                                   |
|                                  | Dust from release agents (chalk stearate or talc)   | Substitution of wet methods<br>Enclosure and local exhaust ventilation                                                                    |
| <b>Curing</b>                    | Fume                                                | Local exhaust ventilation at autoclave door and storage racks<br>Allow autoclave to cool before opening                                   |
| <b>Spreading</b>                 | Fume                                                | Local exhaust ventilation<br>Care in handling mixes                                                                                       |

to health arises due to administration in the course of medical treatment, and substances below ground in mines, which have their own legislation.)

Substances 'hazardous to health' include substances labelled as dangerous (i.e. very toxic, toxic, harmful, irritant or corrosive) under any other statutory requirements, agricultural pesticides and other chemicals used on farms, and substances with occupational exposure limits. They include harmful micro-organisms and substantial quantities of dust. Indeed any material, mixture or compound used at work, or arising from work activities, which can harm people's health is apparently covered.

The regulations set out essential measures that employers (and sometimes employees) have to take:

Prohibit use of substances listed in Table 5.20.

Assess the risk to health arising from work, and what precautions are needed (see Figure 5.3).

**Table 5.20 Prohibition of certain substances hazardous to health for certain purposes**

| <i>Substance</i>                                                                                                                                                                                                                                                              | <i>Purpose for which substance is prohibited</i>                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2-Naphthylamine; benzidine; 4-aminodiphenyl; 4-nitrodiphenyl; their salts and any substance containing any of those compounds, in a total concentration equal to or greater than 0.1% by mass                                                                                 | Manufacture and use for all purposes including any manufacturing process in which the substance is formed                                                                                                                                                                                                                                                          |
| Sand or other substance containing free silica                                                                                                                                                                                                                                | Use as an abrasive for blasting articles in any blasting apparatus                                                                                                                                                                                                                                                                                                 |
| A substance:                                                                                                                                                                                                                                                                  | Use as a parting material in connection with the making of metal castings                                                                                                                                                                                                                                                                                          |
| (a) containing compounds of silicon calculated as silica to the extent of more than 3% by weight of dry material, other than natural sand, zirconium silicate (zircon), calcined china clay, calcined aluminous fireclay, sillimanite, calcined or fused alumina, olivine; or |                                                                                                                                                                                                                                                                                                                                                                    |
| (b) composed of or containing dust or other matter deposited from a fettling or blasting process                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                    |
| Carbon disulphide                                                                                                                                                                                                                                                             | Use in cold-cure process of vulcanizing in the proofing of cloth with rubber                                                                                                                                                                                                                                                                                       |
| Oils other than white oil, or of entirely animal or vegetable origin or entirely of mixed animal and vegetable origin                                                                                                                                                         | Use in oiling the spindles of self-acting mules                                                                                                                                                                                                                                                                                                                    |
| Ground or powdered flint or quartz other than natural sand                                                                                                                                                                                                                    | Use in relation to the manufacture or decoration of pottery for the following purposes:<br>(a) the placing of ware for the biscuit fire;<br>(b) the polishing of ware;<br>(c) as the ingredient of a wash for saggers, trucks, bats, cranks or other articles used for supporting ware during firing; and<br>(d) as dusting or supporting powder in potters' shops |
| Ground or powdered flint or quartz other than:                                                                                                                                                                                                                                | Use in relation to the manufacture or decoration of pottery for any purpose except:                                                                                                                                                                                                                                                                                |
| (a) natural sand; or                                                                                                                                                                                                                                                          | (a) use in a separate room or building for (i) the manufacture of powdered flint or quartz or (ii) the making of frits or glazes or the making of colours or coloured slips for the decoration of pottery;                                                                                                                                                         |
| (b) ground or powdered flint or quartz which forms part of a slop or paste                                                                                                                                                                                                    | (b) use for the incorporation of the substance into the body of ware in an enclosure in which no person is employed and which is constructed and ventilated to prevent the escape of dust                                                                                                                                                                          |
| Dust or powder of a refractory material containing not less than 80% of silica other than natural sand                                                                                                                                                                        | Use for sprinkling the moulds of silica bricks, namely bricks or other articles composed of refractory material and containing not less than 80% of silica                                                                                                                                                                                                         |
| White phosphorus                                                                                                                                                                                                                                                              | Use in the manufacture of matches                                                                                                                                                                                                                                                                                                                                  |
| Hydrogen cyanide                                                                                                                                                                                                                                                              | Use in fumigation except when:<br>(a) released from an inert material in which hydrogen cyanide is absorbed;<br>(b) generated from a gassing powder; or<br>(c) applied from a cylinder through suitable piping and applicators other than for fumigation in the open air to control or kill mammal pests                                                           |
| Benzene and any substance containing benzene in a concentration equal to or greater than 0.1% by mass other than:                                                                                                                                                             | Uses for all purposes except:                                                                                                                                                                                                                                                                                                                                      |
| (a) motor fuels                                                                                                                                                                                                                                                               | (a) use in industrial processes; and                                                                                                                                                                                                                                                                                                                               |
| (b) waste                                                                                                                                                                                                                                                                     | (b) for the purposes of research and development or for the purpose of analysis                                                                                                                                                                                                                                                                                    |
| <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">           } covered by specific EEC Directives         </div> </div>                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                    |

Table 5.20 Cont'd

| <i>Substance</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <i>Purpose for which substance is prohibited</i>                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>The following substances:<br/> chloroform, carbon tetrachloride; 1,1,2-trichloroethane,<br/> 1,1,2,2-tetrachloroethane; 1,1,1,2-tetrachloroethane;<br/> pentachloroethane, vinylidene chloride; 1,1,1-trichloroethane<br/> and any substance containing one or more of those substances<br/> in a concentration equal to or greater than 0.1% by mass,<br/> other than:</p> <ul style="list-style-type: none"> <li>(a) medical products;</li> <li>(b) cosmetic products</li> </ul> | <p>Supply for use at work in diffusive applications such as in<br/> surface cleaning and the cleaning of fabrics except for the<br/> purposes of research and development or for the purpose of<br/> analysis</p> |

Introduce appropriate measures to prevent or control the risk.

Ensure that control measures are used and that equipment is properly maintained and procedures observed.

Where necessary, monitor the exposure of the workers and carry out an appropriate form of surveillance of their health.

Inform, instruct and train employees about the risks and the precautions to be taken.

### **Assessment**

The HSE provide elegant guidance and checklists for conducting and recording risk assessments in *COSHH Essentials* (see Bibliography). This is supplemented by guidance sheets on ventilation, engineering controls and containment for a variety of unit operations including charging reactors; dipping; filling/emptying sacks/kegs/drums; mixing; sieving; weighing.

The basic steps in any assessment include a review of:

#### *1 What substances are present? In what form?*

- (a) Substances brought into the workplace.
- (b) Substances given off during any process or work activity.
- (c) Substances produced at the end of any process or work activity (service activities included).

Substances 'hazardous to health' can be identified by:

for brought-in substances, checking safety information on labels and that legally obtainable from the suppliers, e.g. on their Material Safety Data sheet: making sure it is the most up-to-date version;

use of existing knowledge, e.g. past experience, knowledge of the process, understanding of relevant current best industrial practice, information on related industrial health problems;

seeking advice from a trade association, others in a similar business, consultants;

checking whether a substance is mentioned in any COSHH Regulations or Schedules, or listed in Guidance Note EH 40;

examination of published trade data, HSE guidance information, literature or documentation; checking Part 1 of the approved supply list under the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994. (Anything listed as very toxic, toxic, corrosive, harmful or irritant is covered by COSHH.)

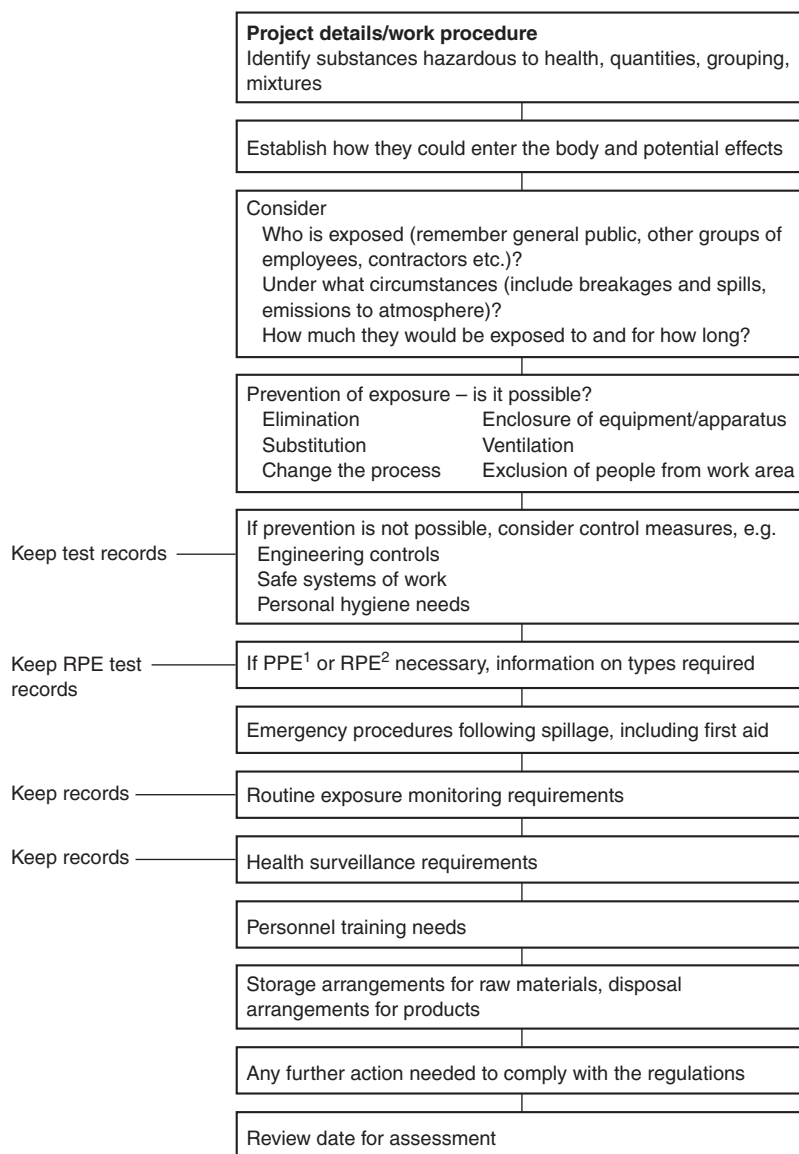


**Figure 5.3** COSHH assessment procedure

<sup>1</sup>PPE = Personal Protective Equipment

<sup>2</sup>RPE = Respiratory Protective Equipment

## 2 What is the health hazard?

if breathed in, on contact with the skin or eyes, or if ingested?

quantity of material used, i.e. small (grams or millilitres), medium (kilograms or litres), or large (tonnes or cubic metres)?

how dusty or volatile is the substance?

*3 Where and how are the substances actually used or handled?*

Where and in what circumstances are the substances handled, used, generated, released, disposed of etc.?

What happens to them in use (e.g. does their form change – such as from bulk solid to dust by machining)?

Identify storage and use areas.

Identify modes of transport.

*4 What harmful substances are given off etc.?*

*5 Who could be affected, to what extent and for how long?*

Identify both employees and non-employees – including cleaners, security staff, employees, contractors, members of the public who could be affected.

*6 Under what circumstances?*

Is some of the substance likely to be breathed in?

Is it likely to be swallowed following contamination of fingers, clothing etc.?

Is it likely to cause skin contamination or be absorbed through the skin? (NB some materials have a definite Sk notation in EH 40.)

Is it reasonably foreseeable that an accidental leakage, spill or discharge could occur (e.g. following an operating error or breakdown of equipment or failure of a control measure)?

Consider:

How are people *normally* involved with the substance?

How might they be involved (e.g. through misuse, spillage)?

*7 How likely is it that exposure will happen?*

Check control measures currently in use.

Check on their effectiveness and whether they are conscientiously/continuously applied.

*8 What precautions need to be taken to comply with the rest of the COSHH Regulations?*

Having regard to

who could be exposed,  
under what circumstances,  
the level and possible length of time,  
how likely exposure is,  
the environmental hazards,

together with knowledge about the hazards of the substance (i.e. its potential to cause harm), conclusions are reached about personal exposure.

The employer's duty is to ensure that the exposure of employees to a hazardous substance is prevented or, if this is not reasonably practicable, adequately controlled. Duties under the Regulations



extend with certain exceptions to other persons, whether at work or not, who may be affected by the employers work.

## **Control**

Prevention of exposure should be given priority, e.g. by:

changing the process or method of work to eliminate the operation resulting in the exposure;  
process modification to avoid production of a hazardous product, by-product or waste product;  
substitution of a hazardous substance by a new, or different form of the same, substance which presents less risk to health.

If for a carcinogen prevention of exposure is not reasonably practicable by using an alternative substance or process there is a requirement to apply *all* the measures listed in Table 5.21. If these measures do not provide adequate control then suitable personal protective equipment as will adequately control exposure must be provided.

**Table 5.21 Measures for the control of exposure to carcinogens**

---

Total enclosure of the process and handling systems unless not reasonably practicable.  
Use of plant, processes and systems of work which minimize the generation of, or suppress and contain, spills, leaks, dust, fumes and vapours.  
Limitation of quantities in the workplace.  
Keeping the number of persons who might be exposed to a minimum.  
Prohibition of eating, drinking and smoking in areas that may be contaminated.  
Provision of hygiene measures including adequate washing facilities and regular cleaning of walls and surfaces.  
Designation of those areas and installations which may be contaminated and the use of suitable and sufficient warning signs.  
Safe storage, handling and disposal, and use of closed and clearly labelled containers.

---

For hazardous substances not classified as carcinogens, where protection of exposure is not reasonably practicable, adequate control should be achieved by measures other than personal protection, so far as is reasonably practicable. This is subject to the degree of exposure, circumstances of use of the substance, informed knowledge about the hazards and current technical developments. Any combination of the measures listed in Table 5.22 are applicable.

**Table 5.22 Measures for the control of exposure to hazardous substances not classified as carcinogens**

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Totally enclosed process and handling systems.  
Plant or processes or systems of work which minimize generation of, or suppress or contain, the hazardous dust, fume, biological agent etc. and limit the area of contamination in the event of spills and leaks.  
Partial enclosure with local exhaust ventilation.  
Local extract ventilation.  
Sufficient general ventilation.  
Reduction of number of employees exposed.  
Exclusion of non-essential access.  
Reduction in the period of exposure for employees.  
Regular cleaning of contamination from, or disinfection of, walls, surfaces etc.  
Provision of means for safe storage and disposal.  
Prohibition of eating, drinking, smoking, application of cosmetics etc. in contaminated areas.  
Provision of adequate facilities for washing, changing and storage of clothing, with arrangements for laundering contaminated clothing.

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Again when the measures in Table 5.22 do not prevent, or provide adequate control of exposure there is a requirement to provide suitable personal protective equipment to accomplish it. This includes respiratory protection, protective clothing generally, footwear and eye protection which, in the UK, complies with the Personal Protective Equipment Regulations 1992. All routes of exposure, e.g. inhalation, ingestion, absorption through the skin or contact with the skin, must be considered.

Control measures in existing work situations should be reviewed, extended or replaced as necessary to achieve and sustain adequate control.

If leaks, spills or uncontrolled releases of a hazardous substance could occur, means are required for limiting the extent of health risks and for regaining adequate control as soon as possible. Where appropriate means should include:

- establish emergency procedures;
- safe disposal of the substance;
- sufficient suitable personal protective equipment to enable the source of the release to be safely identified and repairs to be made;
- exclusion of all persons not concerned with the emergency action from the area of contamination;
- in the case of carcinogens, ensuring that employees and other persons who may be affected by an escape into the workplace are kept informed of the failure forthwith.

### ***Exposure limits***

Exposures require control such that nearly all people would not suffer any adverse health effects even if exposed to a specific substance (or mixture of substances) day after day. For certain substances there are set occupational exposure limits: refer to page 78.

As noted earlier, routes other than inhalation must also be considered. Thus exposure to a substance which can be hazardous upon ingestion, absorption through the skin or mucous membranes, or contact with skin or mucous membranes needs control to a standard such that nearly all the population could be exposed repeatedly without any adverse health effect. (Note that this will not necessarily protect those who are atopic or with a relevant pre-existing condition, e.g. dermatitis.)

### ***Maintenance, examination and testing of control measures***

An employer has specific obligations to ensure all control measures are kept in an efficient state, efficient working order and good repair. Engineering controls should be examined and tested at suitable intervals, e.g. local exhaust ventilation equipment must be tested at least once every fourteen months, and more often for processes specified in Table 5.23, and a record kept. Respirators and breathing apparatus must also be examined frequently and the checks recorded.

### ***Monitoring***

The exposure of workers should be monitored in certain cases, e.g.

- substances or processes listed in Table 5.24;
- where it is not certain that particular control measures are working properly;
- where it is not possible to be sure that exposure limits are not being exceeded;
- where there could be serious risks to health if control measures were to fail or deteriorate.

**Table 5.23 Frequency of thorough examination and test of local exhaust ventilation plant used in certain processes (Schedule 4, Reg. 9(2)(a))**

| <i>Process</i>                                                                                                                                                                                          | <i>Minimum frequency</i> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Blasting in, or incidental to cleaning of metal castings, in connection with their manufacture                                                                                                          | 1 month                  |
| Processes, other than wet processes, in which metal articles (other than gold, platinum or iridium) are ground, abraded or polished using mechanical power, in any room for more than 12 hours per week | 6 months                 |
| Processes giving off dust or fume in which non-ferrous metal castings are produced                                                                                                                      | 6 months                 |
| Jute cloth manufacture                                                                                                                                                                                  | 1 month                  |

**Table 5.24 Specific substances and processes for which monitoring is required (Schedule 5, Reg. 10(2))**

| <i>Substance or process</i>                                                                                     | <i>Minimum frequency</i>                                                                 |
|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Vinyl chloride monomer                                                                                          | Continuous or in accordance with a procedure approved by the Health and Safety Executive |
| Spray liberated from vessels at which an electrolytic chromium process is carried on, except trivalent chromium | Every 14 days while the process is being carried on                                      |

A record should be kept of any monitoring for at least 5 years, unless it is representative of personal exposure of identifiable employees when records must be retained for at least 40 years.

### ***Personal/workplace air monitoring***

Sampling strategies may include measurement of the hazardous substance:

- in the breathing zone of a worker (personal dosimetry); and/or
- in the workplace air (see Chapter 10).

### ***Biological monitoring***

For a few substances exposure may be assessed using biological monitoring (see page 114). Depending upon the substance the sampling strategy varies from post shift, random, or pre-shift the day after exposure.

### ***Health surveillance***

If a known adverse health effect can reasonably be anticipated under the circumstances of work – and could readily be observed – some form of health surveillance is appropriate. This may involve a doctor or trained nurse. It may include the checking of employees' skin for dermatitis or asking questions relevant to any asthmatic condition where work is with recognized causative agents (e.g. epoxy resin curing agents).

In the UK health surveillance is a statutory requirement for the agents, operations and processes

summarized in Table 5.25. Advice on health surveillance is also given for the agents listed in Table 5.26.

**Table 5.25 UK health surveillance requirements**

| <b>Medical surveillance is required unless exposure is insignificant</b> (Schedule 6 to COSHH Reg. 11(2)a and 5)            |                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Substance</i>                                                                                                            | <i>Process</i>                                                                                                                                                                                                             |
| Vinyl chloride monomer (VCM)                                                                                                | In manufacture, production, reclamation, storage, discharge, transport, use or polymerization                                                                                                                              |
| Nitro or amino derivatives of phenol and of benzene or its homologues                                                       | In the manufacture of nitro or amino derivatives of phenol and of benzene or its homologues and the making of explosives with the use of any of these substances                                                           |
| Potassium or sodium chromate or dichromate                                                                                  | In manufacture                                                                                                                                                                                                             |
| Orthotolidine and its salts                                                                                                 | In manufacture, formation or use of these substances                                                                                                                                                                       |
| Dianisidine and its salts                                                                                                   |                                                                                                                                                                                                                            |
| Dichlorobenzidine and its salts                                                                                             |                                                                                                                                                                                                                            |
| Auramine                                                                                                                    | In manufacture                                                                                                                                                                                                             |
| Magenta                                                                                                                     |                                                                                                                                                                                                                            |
| Carbon disulphide                                                                                                           | Processes in which these substances are used, or given off as vapour, in the manufacture of indiarubber or of articles or goods made wholly or partially of indiarubber                                                    |
| Disulphur dichloride                                                                                                        |                                                                                                                                                                                                                            |
| Benzene, including benzol                                                                                                   |                                                                                                                                                                                                                            |
| Carbon tetrachloride                                                                                                        |                                                                                                                                                                                                                            |
| Trichloroethylene                                                                                                           |                                                                                                                                                                                                                            |
| Pitch                                                                                                                       | In manufacture of blocks of fuel consisting of coal, coal dust, coke or slurry with pitch as a binding substance                                                                                                           |
| <b>Health surveillance is appropriate unless exposure is insignificant</b> (Control of Carcinogenic Substances ACOP, 15–18) |                                                                                                                                                                                                                            |
| Asbestos                                                                                                                    | <i>Selected relevant legislation</i><br>Control of Asbestos at Work Regulations 1987 and subsequent amendments                                                                                                             |
| Compressed air (other than diving operations)                                                                               | Work in Compressed Air Special Regulations 1958                                                                                                                                                                            |
| Diving operations                                                                                                           | Diving Operations at Work Regulations 1981 and subsequent amendments                                                                                                                                                       |
| Flint, quartz, transfers, colours, frits, glazes, dusts                                                                     | Approved Code of Practice. Control of substances hazardous to health in the production of pottery.<br>Control of substances hazardous to health regulations.                                                               |
| Ionizing radiations                                                                                                         | Ionizing Radiations Regulations 1999                                                                                                                                                                                       |
| Lead                                                                                                                        | Control of lead at Work Regulations 1998                                                                                                                                                                                   |
| Pesticides                                                                                                                  | MAFF/HSC Code of Practice for the safe use of pesticides on farms and holdings.<br>Approved Code of Practice. Safe use of pesticides for non-agricultural purposes. Control of substances hazardous to health regulations. |

Health records must be kept of the health surveillance carried out for at least 40 years after the last entry. Appropriate action should be taken based upon the results, i.e. it should be established how and when workers should be referred for further examination and how the results will be used to improve the management of health risks.

**Table 5.26 Agents for which health surveillance is advised**

| <i>Agent</i>                        | <i>UK HSE Guidance Note</i> |
|-------------------------------------|-----------------------------|
| Agents liable to cause skin disease | EH 26                       |
| Antimony                            | EH 19                       |
| Arsenic                             | EH 8                        |
| Beryllium                           | EH 13                       |
| Cotton dust                         | MS 9                        |
| Agents causing genetic modification | ACGM/HSE Note 4             |
| Isocyanates                         | { EH 16                     |
|                                     | { MS 8                      |
| Mineral wool                        | EH 46                       |
| Platinum                            | MS 22                       |
| Talc dust                           | EH 32                       |
| <b>Biological monitoring</b>        |                             |
| Cadmium                             | EH 1                        |
| Mercury                             | { EH 17                     |
|                                     | { MS 12                     |
| Trichloroethylene                   | EH 5                        |
| <b>Biological effect monitoring</b> |                             |
| Organophosphorus pesticides         | MS 17                       |

### ***Information supply***

There is requirement to train and inform employees of:

- the risks arising from their work
- the precautions to be taken
- the results of any monitoring carried out
- the collective (anonymous) results of any health surveillance carried out.

### **Specific precautions**

Ways in which these principles are applied in practice are illustrated in the following section using common potentially hazardous operations or substances:

- Everyday operations such as painting and welding.
- Toxic dusts such as asbestos and catalysts.
- Hyperpoisons such as cyanides.
- Insecticides.
- Primary irritants and corrosives.
- Common gases such as oxides of carbon and nitrogen, hydrogen sulphide, and inert gases.
- Liquids which pose a health hazard due to volatilization, e.g. mercury and degreasing with chlorinated solvent, i.e. dry cleaning with perchloroethylene or metal cleaning with trichloroethylene.
- Liquids posing problems because of the presence of impurities, e.g. mineral oils.
- Use of a strong disinfectant/biocide, i.e. glutaraldehyde.
- Machining operations on metals involving cooling by fluids.
- Application of synthetic resins, e.g. epoxy resins.
- Gases present in buildings, e.g. offices.

*(i) Asbestos*

This ubiquitous material previously found use in construction materials, lagging, brake linings etc. If inhaled, asbestos dust may result in serious respiratory disease (e.g. asbestosis, lung cancer, mesothelioma of the pleura). Therefore strict control must be exercised over all work with asbestos products which may give rise to dust. Within the UK, the Control of Asbestos at Work Regulations 1987 as amended by the Control of Asbestos at Work (Amendment) Regulations 1992 and 1998, and Approved Codes of Practice apply to all such work, including manufacturing, processing, repairing, maintenance, construction, demolition, removal and disposal. Because of their wider relevance their requirements are summarized in Table 5.27.

*(ii) Catalysts*

Catalysts are often used to increase the rate of reactions (Chapter 3). Like many chemicals they can pose health risks to workers (Table 5.28) unless handled with care. They can be either:

homogeneous catalysts dispersed with reactants so that reaction takes place in a single phase. The catalyst is added to the reactor with other process ingredients and removed by the normal finishing separation processes. Worker exposure is similar to those for other process materials; heterogeneous catalysts where the catalysis occurs at a solid interface, often used in the form of fixed beds. These must be regenerated or replaced periodically posing significant exposure risks.

Heterogeneous catalysts are often located at the top of a reactor and manipulated with temporary handling equipment. To avoid exposure to toxic dust, local ventilation should be installed; if this is impracticable, scrupulous use of personal protective equipment and rigid compliance with systems-of-work are essential. Respiratory equipment may include self-contained or line-fed breathing apparatus.

Skin protection may necessitate use of full protective suits. When catalysts are dumped from reactors at the end of a process they may prove to be extremely dusty as a result of reduction in particle size during the reaction process. Again, depending upon the nature of the hazard, ventilation, personal protection, and use of temporary enclosures to prevent contamination of the general work area should be considered. Some catalysts are pyrophoric and some catalyst beds are inerted with the added possibility of fire, or release of inerting gas into the workplace which may cause asphyxiation.

Aluminium oxide may induce respiratory irritation upon inhalation of high concentrations resulting in emphysema and flu-like symptoms. Some catalysts are sensitive to exposure to moist air. Aluminium alkyls may be pyrophoric and personal protection must be worn to prevent skin burns. Aluminium chloride reacts with moisture in air to produce steam and irritant hydrogen chloride and with moisture in the eyes, mucous membranes or skin. It is on the basis that 3 moles of hydrogen chloride with a ceiling TLV of 5 ppm hydrolyse from one mole of  $\text{AlCl}_3$ , that an 8 hr TWA TLV of  $2 \text{ mg/m}^3$  for  $\text{AlCl}_3$  as Al has been set to offer the same degree of freedom from irritation that is provided by the TLV for HCl. The material should therefore be stored in a cool, dry, well-ventilated place and the bulk stocks must be waterproof and segregated from combustibles. Pressure build-up due to evolution of hydrogen chloride should be safely vented. Depending upon scale of operation, goggles, face-shield, gloves, shoes and overalls of acid-resistant materials should be worn. Transfer should be in dry air or under a nitrogen blanket. Process fumes/dust should be collected via a scrubber. Spillages should be collected before washing the area with copious volumes of water.

**Table 5.27 Summary of precautions for work involving asbestos**

|                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|----------------------|----------------------------------------|---------------------|--------------------------------------------------------------------------|----|--------------------------------------------------------------------------------|------------------------|
| Assessment                                                                     | Before starting any work which is liable to expose employees to asbestos dust, an assessment of the work is required to help decide the measures necessary to control exposure. This should:<br><br>Identify the type of asbestos (or assume that it is crocidolite or amosite, to which stricter controls are applicable than to chrysotile).<br>Determine the nature and degree of exposure.<br>Set out steps to be taken to prevent that exposure, or reduce it to the lowest level reasonably practicable.<br><br>The assessment should be in writing except if the work involves low level exposure and is simple, so that the assessment can be easily repeated and explained.                                                                                                                                                                                                                                                       |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
| Control limits                                                                 | (Fibres per millimetre)<br>chrysotile<br>any other form of asbestos alone<br>or in mixtures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 4 hrs<br>0.3<br>0.2 | 10 min<br>0.9<br>0.6 |                                        |                     |                                                                          |    |                                                                                |                        |
|                                                                                | Employees should never breathe air containing a level of asbestos which exceeds these limits. Moreover the level should always be reduced so far as it reasonably can be. Use should be made of:<br><br>Suitable systems of work.<br>Exhaust ventilation equipment.<br>Other technical measures.<br>All of these techniques if reasonably practicable.<br><br>If the dust level is, or could be, above the control limit an employer must:<br><br>Provide suitable respiratory protective equipment and ensure that it is used properly.<br>Post warning notices that the area is a 'respirator zone'.                                                                                                                                                                                                                                                                                                                                     |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
| Action levels                                                                  | Action levels are a measure of the total amount of asbestos to which a person is exposed within a 12 week period. These are set in fibres/hr per millilitre:<br><br><table><tr><td>where exposure is solely to chrysotile</td><td>over 12 weeks<br/>72</td></tr><tr><td>where exposure is to any other form of asbestos,<br/>alone or in mixtures</td><td>48</td></tr><tr><td>where both types of exposure occur in the 12 week<br/>period at different times</td><td>a proportionate number</td></tr></table><br>When these are, or may be, exceeded the employer must ensure that the enforcing authority has been notified, maintain a health record of exposed workers and make sure that they receive regular medical examinations, and identify work areas where the action level is liable to be exceeded as 'asbestos areas'.                                                                                                      |                     |                      | where exposure is solely to chrysotile | over 12 weeks<br>72 | where exposure is to any other form of asbestos,<br>alone or in mixtures | 48 | where both types of exposure occur in the 12 week<br>period at different times | a proportionate number |
| where exposure is solely to chrysotile                                         | over 12 weeks<br>72                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
| where exposure is to any other form of asbestos,<br>alone or in mixtures       | 48                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
| where both types of exposure occur in the 12 week<br>period at different times | a proportionate number                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |
| Other provisions                                                               | There are also requirements for an employer to:<br><br>Monitor the exposure of employees to asbestos where appropriate.<br>Ensure that employees liable to be exposed to asbestos receive adequate information, instruction and training – so that they are aware of the risks and the precautions which should be observed.<br>Provide protective clothing for workers when a significant quantity of asbestos is liable to be deposited on their clothes.<br>Check that the plant or premises where work with asbestos is carried out is kept clean.<br>Make sure that there are adequate washing and changing facilities.<br>Provide separate storage areas for any protective clothing and respiratory protective equipment required, and for personal clothing.<br>Make sure that all asbestos articles, substances and products for use at work are specially labelled.<br>Keep raw asbestos and asbestos waste sealed and labelled. |                     |                      |                                        |                     |                                                                          |    |                                                                                |                        |

**Table 5.28 Health effects of catalysts**

| <i>Catalyst</i>      | <i>Uses</i>                                                                                                                                                       | <i>Health effect</i>                                                                  |
|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Aluminium oxide      | Hydrotreating petroleum feedstocks<br>Fluid cracking<br>Autoexhausts                                                                                              | Nuisance                                                                              |
| Aluminium chloride   | Resin manufacture by polymerization of low molecular-weight hydrocarbons<br>Friedel–Crafts reactions to manufacture detergent alkylate, agrochemicals, drugs      | Irritation due to formation of HCl with moisture                                      |
| Aluminium alkyls     | Alkylations/Grignard reactions                                                                                                                                    | Acute thermal burns, lung damage                                                      |
| Chromic oxide        |                                                                                                                                                                   | Cr <sup>3+</sup> may be converted to the more toxic and carcinogenic Cr <sup>6+</sup> |
| Colbalt              | Hydrogenations of solid fuels and fuel oils<br>Manufacture of terephthalic acid<br>High pressure production of aldehydes                                          | Lung irritation (hard metal disease); respiratory sensitization                       |
| Ferric oxide         | Oxidations                                                                                                                                                        | Siderosis                                                                             |
| Molybdenum compounds | Hydrodesulphurization and hydrotreating of petroleum<br>Oxidation of methanol to formaldehyde<br>Epoxidation of olefins<br>Decomposition of alkali metal nitrides | Irritation of eyes and respiratory tract<br>Pneumoconiosis                            |
| Nickel compounds     | Hydrogenations (e.g. Raney nickel)<br>Conversion of synthesis gas to methane<br>Reduction of organo nitro compounds to amines                                     | Carcinogenic (nickel subsulphide).<br>Skin sensitization                              |
| Nickel carbonyl      | Carbonylation of acetylene and alcohols to produce acrylic and methacrylic acids                                                                                  | Acute respiratory failure; carcinogenic                                               |
| Platinum compounds   | Hydrosilation cross-linking of silicone polymers<br>Hydrogenation, isomerization and hydroformylation of alkenes<br>Automobile exhaust catalyst                   | Sensitization dermatitis                                                              |
| Vanadium             | Pollution control, e.g. removal of hydrogen sulphide and in manufacture of sulphuric acid                                                                         | Respiratory irritation; green–black tongue (transient)                                |

Chromium oxide and chromium supported on other oxides such as aluminium oxide are important catalysts for a wide range of reactions. Chromium forms several oxides, the most important of which are Cr<sub>2</sub>O<sub>3</sub>, CrO<sub>2</sub> and CrO<sub>3</sub>. None are without problems and whilst it is often thought that trivalent Cr compounds are of low toxicity, dermatitis and pulmonary disease may result from exposure. The hexavalent compounds such as CrO<sub>3</sub> are more toxic with potential to cause irritant and allergic contact dermatitis, skin ulcers (including ‘chrome holes’), nasal irritation and kidney damage. Some water-insoluble compounds have been associated with an increased risk of lung cancer. An 8 hr TWA MEL has been set at 0.05 mg/m<sup>3</sup> for Cr VI compounds. CrO<sub>3</sub> can react with reducing agents including organic compounds (e.g. acetic acid, aniline, quinoline, alcohol, acetone, thinners, and grease) vigorously to cause fires and explosions. On heating to 250 °C it liberates oxygen to further support combustion. Containment, or use of ventilation, and personal protective equipment such as rubber gloves, respirators, overalls, rubber aprons, rubber boots may be necessary depending upon the risk and nature of exposure. If the process is routine, atmospheric analysis and biological monitoring backed up with health surveillance may also be required. Stocks should be protected from physical damage, stored in a dry place away from combustible materials and easily oxidizable substances. Avoid storage on wooden floors.



Long-term exposure to ferric oxide dust can cause changes to the lungs which are detectable by X-rays. For this reason an 8 hr TWA TLV of  $5 \text{ mg/m}^3$  has been set. Good ventilation is important for processes involving this compound. For regular use routine medical examination and exclusion of staff with pulmonary disease may be necessary.

Some nickel compounds may be irritant to skin and eyes and dermal contact with nickel can result in allergic contact dermatitis. Nickel carbonyl is extremely toxic by inhalation and should be handled in totally enclosed systems or with extremely efficient ventilation. Air monitors linked to alarms may be required to detect leaks. Respiratory equipment must be available for dealing with leaks. Biological checks (e.g. nickel in urine) should be considered for routine operations involving nickel catalysts.

Platinum is used as a catalyst for nitric and sulphuric acid production, in petroleum refining and in catalytic mufflers to control air pollution. Platinum salts can cause respiratory complaints, asthma, and 'platinosis', an allergic response. Allergic dermatitis may also result from exposure to soluble platinum salts and once subjects have been sensitized it generally precludes continued occupational exposure at any level. The 8 hr TWA OEL for platinum metal is  $5 \text{ mg/m}^3$  but for soluble platinum salts it is only  $0.002 \text{ mg/m}^3$ . Handling precautions must include containment where possible, ventilation, personal protection, and the screening out of individuals who have become sensitized.

Vanadium as the pentoxide is used as a catalyst in the oxidation of sulphur dioxide, oxides of nitrogen, and other substances. Vanadium is poisonous by any route in any but small doses and the pentavalent state, such as  $\text{V}_2\text{O}_5$ , is the most hazardous. Upon inhalation, the main effects are on the respiratory passages causing tracheitis, bronchitis, emphysema, pulmonary edema, or bronchial pneumonia. Symptoms of acute exposure may include nausea, vomiting, high temperature, diarrhoea, nervous malfunction and frequent coughs whilst those of chronic exposure are pale skin, anaemia, vertigo, cough, high blood pressure, green discoloration of tongue, tremor of fingers and nervous malfunction. In animal studies exposure to  $70 \text{ mg/m}^3$   $\text{V}_2\text{O}_5$  dust was fatal within a few hours. An 8 hr TWA TLV of just  $0.05 \text{ mg/m}^3$  has been set in the USA by the ACGIH. Clearly, processes must be designed such that dust formation is prevented. Where exposure is possible ventilation, personal protection including respiratory protection, medical surveillance, atmospheric monitoring and high standards of personal hygiene should be considered to ensure exposure is controlled.

### (iii) *Common gases* (see also *Chapter 9*)

#### (a) *Carbon dioxide*

Carbon dioxide gas can act as an asphyxiant due to displacement of air, resulting in oxygen deficiency (page 262). Sources include:

- Fires, because it is inevitably a product of combustion from any carbon-based fuel.
- Use as an inert gas.
- Discharge of carbon dioxide extinguishers.
- Use of solid 'cardice' as a cryogen (page 261).
- Natural processes, e.g. fermentation.
- Water from certain underground strata, due to de-gassing (page 46).
- The neutralization of acids with carbonates or bicarbonates.
- As a byproduct of the synthesis of ammonia, hydrogen.

The hazard is particularly acute in confined spaces.

The gas is also toxic as exemplified by Table 5.29. Furthermore, the increased respiratory rate may cause increased amounts of other toxic gases, e.g. carbon monoxide in fires, to be inhaled.

**Table 5.29 Typical reactions of persons to carbon dioxide in air**

| <i>Carbon dioxide concentration (ppm)</i> | <i>(%)</i> | <i>Effect</i>                                                                              |
|-------------------------------------------|------------|--------------------------------------------------------------------------------------------|
| 5000                                      | 0.5        | TLV/OEL-TWA: can be tolerated for 8 hr exposure with no symptoms and no permanent damage   |
| 15 000                                    | 1.5        | OEL-STEL: 10 min                                                                           |
| 20 000                                    | 2.0        | Breathing rate increased by 50%                                                            |
| 30 000                                    | 3.0        | TLV-STEL: breathing rate increased by 100%                                                 |
| 50 000                                    | 5.0        | Vomiting, dizziness, disorientation, breathing difficulties after 30 min                   |
| 80 000                                    | 8.0        | Headache, vomiting, dizziness, disorientation, breathing difficulties after short exposure |
| 100 000                                   | 10.0       | Headache, vomiting, dizziness, disorientation, unconsciousness, death after a few minutes  |

The special precautions appropriate for entry into confined spaces are summarized in Chapter 13. In fires, evacuation of burning buildings, prohibition on re-entry and the use of self-contained breathing apparatus by fire-fighters are key precautions.

*(b) Carbon monoxide*

Carbon monoxide is a colourless, odourless gas and – without chemical analysis – its presence is undetectable. It is produced by steam reforming or incomplete combustion of carbonaceous fuels; typical carbon monoxide concentrations in common gases are given in Table 5.30.

**Table 5.30 Typical carbon monoxide concentrations in gases**

| <i>Gas</i>                       | <i>Typical carbon monoxide concentration (%)</i> |
|----------------------------------|--------------------------------------------------|
| Blast furnace gas                | 20–25                                            |
| Coal and coke oven gas           | 7–16                                             |
| Natural gas, LPG (unburnt)       | nil                                              |
| Petrol or LPG engine exhaust gas | 1–10                                             |
| Diesel engine exhaust gas        | 0.1–0.5                                          |

Carbon monoxide is extremely toxic by inhalation since it reduces the oxygen-carrying capacity of the blood. In sufficient concentration it will result in unconsciousness and death. Typical reactions to carbon monoxide in air are summarized in Table 5.31.

**Table 5.31 Typical reactions of persons to carbon monoxide in air**

| <i>Carbon monoxide (ppm)</i> | <i>Effect</i>                                                                               |
|------------------------------|---------------------------------------------------------------------------------------------|
| 30                           | Recommended exposure limit (8 hr time-weighted average concentration)                       |
| 200                          | Headache after about 7 hr if resting or after 2 hr exertion                                 |
| 400                          | Headache with discomfort with possibility of collapse after 2 hr at rest or 45 min exertion |
| 1200                         | Palpitation after 30 min at rest or 10 min exertion                                         |
| 2000                         | Unconscious after 30 min at rest or 10 min exertion                                         |

The STEL is 200 ppm but extended periods of exposure around this, particularly without interruption, raise concern for adverse health effects and should be avoided.

If a potential carbon monoxide hazard is identified, or confirmed by atmospheric monitoring, the range of control techniques summarized on page 280 must be applied.

### *(c) Hydrogen sulphide*

Hydrogen sulphide occurs naturally, e.g. in gases from volcanoes, undersea vents, swamps and stagnant water. It is also a byproduct of many industrial processes, e.g. coking and hydrodesulphurization of crude oil or coal. It is a highly toxic gas. Although readily detectable by odour at low concentrations, at high concentrations it paralyses the sense of smell and the nervous system controlling the lungs and hence acts as a chemical asphyxiant. Typical effects at different concentrations in air are summarized in Table 5.32.

**Table 5.32 Typical effects or hydrogen sulphide concentrations in air**

| <i>Concentration (ppm)</i> | <i>Response</i>                                |
|----------------------------|------------------------------------------------|
| 0.2                        | Detectable odour                               |
| 20–150                     | Conjunctivitis                                 |
| 150                        | Olfactory nerve paralysis                      |
| 250                        | Prolonged exposure may cause pulmonary oedema  |
| 500                        | Systemic symptoms may occur in 0.5 to 1 hr     |
| 1000                       | Rapid collapse, respiratory paralysis imminent |
| 5000                       | Immediately fatal                              |

A hazard of hydrogen sulphide may be present in petroleum refining and recovery involving sour crudes, due to chemical breakdown of sulphides (e.g. by acids), or from anaerobic decomposition of sulphur-containing materials, e.g. in wells, sewers or underground pumping stations. Further properties and cylinder-handling precautions are given in Chapter 9. If hydrogen sulphide exposure is possible environmental levels should be monitored and if necessary ventilation provided and respiratory protection worn.

### *(d) Inert gases*

Most toxicologically inert gases, e.g. nitrogen, argon, helium (and indeed common flammable gases, e.g. hydrogen, methane, propane, butane, acetylene) can generate oxygen-deficient atmospheres. These occur most often within confined spaces but may also be present near vents or open manways. The gases have no colour, smell or taste. Responses at given depleted oxygen levels are summarized in Table 5.7: to reduce the oxygen content to a fatal level requires a simple added asphyxiant gas concentration of approximately 50%.

Oxygen deficiency may arise through, for example:

Use of nitrogen or argon to exclude air from vessels.

Use of carbon dioxide fire extinguishers in a confined space.

Excessive generation of e.g. nitrogen or helium gas from cryogenic liquids.

Leakage of argon from an argon arc welding set in an unventilated enclosure.

Formation of rust inside a closed steel tank (oxygen is removed from the atmosphere by the oxidation of iron).

Neutralizing vessel contents with carbonate or bicarbonate, displacing the air with carbon dioxide.

Entry into a confined space requires strict control (page 417). Whenever oxygen deficiency may be encountered air quality checks should be made and appropriate breathing apparatus used.

*(e) Oxides of nitrogen*

Oxides of nitrogen comprise nitrous oxide ( $\text{N}_2\text{O}$ ), nitric oxide ( $\text{NO}$ ), nitrogen dioxide ( $\text{NO}_2$ ), dinitrogen tetroxide ( $\text{N}_2\text{O}_4$ ) and dinitrogen pentoxide ( $\text{N}_2\text{O}_5$ ).  $\text{N}_2\text{O}_5$  is a low-melting solid rapidly decomposing in air to  $\text{NO}_2/\text{N}_2\text{O}_4$  and nitrogen hexoxide ( $\text{NO}_3$ ). (The last is stable only below  $-142^\circ\text{C}$  above which it decomposes into oxygen and nitrogen dioxide.)

Nitrous oxide is a colourless, non-flammable, non-corrosive gas with sweetish odour and taste. It is generally considered to be non-toxic and non-irritating but one of its main applications is use, in combination with air or oxygen, as a weak anaesthetic in medicine and dentistry. At low concentrations it produces hysteria (hence the term 'laughing gas'). A higher than expected incidence of spontaneous abortions among female workers exposed directly to anaesthetic gases has been reported but the current 8 hr TWA OES (page 99) of 100 ppm is believed sufficiently low to prevent embryofetal toxicity in humans. At high concentrations in the absence of air it is a simple asphyxiant. It is also used as a dispersing agent in whipping cream. It is oxidized in air to the dioxide. 'Nitrous fume' exposure in the main involves the inhalation of airborne  $\text{NO}_2/\text{N}_2\text{O}_4$  mixtures – usually in an equilibrium ratio of approximately 3:7 – which at high concentrations exist as a reddish-brown gas. Sources of fume include:

Fuming nitric acid.

Chemical reactions with nitrogen-based chemicals, including the firing of explosives.

Electric arc welding, flame-cutting using oxy-acetylene, propane or butane flames, or such flames burning in air.

Forage tower silos.

The exhaust of metal-cleaning processes.

Fires, e.g. involving ammonium nitrate.

Exhausts from diesel vehicles.

The effects of this mixture of gases are insidious: several hours may elapse before lung irritation develops. It is feebly irritant to the upper respiratory tract due to its relatively low solubility.

Effects of given concentrations of nitrogen oxides are listed in Table 5.33: the margin between concentrations that provoke mild symptoms and those proving to be fatal is small. A person with a normal respiratory function may be affected by exposure to as low as 5 ppm; diseases such as bronchitis may be aggravated by such exposures. The current 8 hr TWA OES is 3 ppm with an STEL (page 99) of 5 ppm.

**Table 5.33 Effects of nitrogen oxides**

| Concentration<br>(ppm in air) | Effect                                                       |
|-------------------------------|--------------------------------------------------------------|
| <60                           | No warning effect (although the odour threshold is <0.5 ppm) |
| 60–150                        | Can cause irritation and burning in nose and throat          |
| 100–150                       | Dangerous in 30–60 minutes                                   |
| 200–700                       | Fatal on short exposure ( $\leq 1$ hour)                     |

First-aid measures for people exposed to nitrogen dioxide are mentioned in Chapter 9. In any event, containment, ventilation and/or appropriate respiratory protection should be considered depending upon scale of operation and level of exposure.

*(iv) Cyanides*

As a group, the cyanides are among the most toxic and fast-acting poisons. (This is due to the cyanide ion which interferes with cellular oxidation.)

Hydrogen cyanide (prussic acid) is a liquid with a boiling point of 26 °C. Its vapour is flammable and extremely toxic. The effects of acute exposure are given in Table 5.34. This material is a basic building block for the manufacture of a range of chemical products such as sodium, iron or potassium cyanide, methyl methacrylate, adiponitrile, triazines, chelates.

**Table 5.34 Toxic effects of hydrogen cyanide**

| <i>Concentration in air<br/>(ppm)</i> | <i>Effect</i>                                            |
|---------------------------------------|----------------------------------------------------------|
| 2–5                                   | Odour detectable by trained individual                   |
| 10                                    | (UK MEL 10 mg/m <sup>3</sup> STEL (SK))                  |
| 18–36                                 | Slight symptoms after several hours                      |
| 45–54                                 | Tolerated for 3–60 min without immediate or late effects |
| 100                                   | Toxic amount of vapours can be absorbed through skin     |
| 110–135                               | Fatal after 30–60 min, or dangerous to life              |
| 135                                   | Fatal after 30 min                                       |
| 181                                   | Fatal after 10 min                                       |
| 270                                   | Immediately fatal                                        |

Although organocyanides (alkyl cyanides, nitriles or carbonitriles), in which the cyanide group is covalently bonded, tend as a class to be less toxic than hydrogen cyanide, many are toxic in their own right by inhalation, ingestion or skin absorption. Some generate hydrogen cyanide under certain conditions, e.g. on thermal degradation.

The properties of selected cyanides of industrial importance are summarized in Table 5.35.

Depending upon scale of operation, precautions for cyanides include:

techniques to contain substances and avoid dust formation (solid cyanides), aerosol formation (aqueous solutions), and leakages (gas);  
gloves, face and hand protection;  
high standards of personal hygiene;  
ventilation and respiratory protection (dust or gaseous forms);  
environmental monitoring for routine processes;  
health surveillance.

*(v) Glutaraldehyde*

Glutaraldehyde (1,3-diformyl propane) is a powerful, cold disinfectant. It is used principally in aqueous solution as a biocide and chemical disinfectant. It has been widely used in the health services, e.g. in operating theatres, endoscopy units, dental units and X-ray film processing.

The hazards with glutaraldehyde are those of irritation to the skin, eyes, throat, and lungs. It can cause dermal and respiratory sensitization, resulting in rhinitis and conjunctivitis or asthma. In the UK the Maximum Exposure Limit is just 0.05 ppm (8 hr TWA limit) and 0.05 ppm (15 min STEL) with a 'Sen' notation (p. 93).

Wherever practicable it is advisable for glutaraldehyde to be replaced by a less hazardous chemical, e.g. it should not be used as a general wipe-down disinfectant.

Table 5.35 Selected cyano compounds

| <i>Chemical</i>                                                                                        | <i>Toxicity</i>                                                                                                                                                                                                                                              | <i>Properties</i>                                                                                                                            |
|--------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Acetone cyanohydrin</b><br>(Oxyisobutyric nitrile)<br>$(\text{CH}_3)_2\text{C}(\text{OH})\text{CN}$ | Highly toxic by inhalation or ingestion<br>Irritating and moderately toxic upon skin contact<br>Readily decomposes to HCN and acetone at 120 °C, or at lower temperatures when exposed to alkaline conditions                                                | Colourless combustible liquid<br>Flash point 73 °C<br>Ignition temperature 68.7 °C<br>Completely soluble in water                            |
| <b>Acetonitrile</b><br>(Methyl cyanide)<br>$\text{CH}_3\text{CN}$                                      | Highly toxic by ingestion, inhalation or skin absorption<br>Insufficient warning properties. Lethal amounts can be absorbed without great discomfort<br>High concentrations rapidly fatal<br>Possibility of severe delayed reactions                         | Colourless liquid with ether odour and sweet burning taste<br>Flash point 73 °C<br>Ignition temperature 52.3 °C<br>Flammable limits 4.4%–16% |
| <b>Acrylonitrile</b><br>(Vinyl cyanide)<br>$\text{CH}_2\text{CHCN}$                                    | Closely resembles HCN in toxic action<br>Poisonous by inhalation, ingestion or skin absorption<br>Emits cyanides when heated or contacted by acids or acid fumes<br>Symptoms: flushed face, irritation of eyes and nose, nausea etc.                         | Colourless flammable liquid with mild, faintly pungent odour<br>Flash point 0 °C. Dilute water solutions also have low flash points          |
| <b>Adiponitrile</b><br>(Tetramethylene cyanide)<br>$\text{CN}(\text{CH}_2)_4\text{CN}$                 | Can behave as a cyanide when ingested or otherwise absorbed into the body<br>Combustion products may contain HCN                                                                                                                                             | Water-white, practically odourless liquid<br>Flash point 93 °C<br>Specific gravity 0.97<br>Vapour density 3.7                                |
| <b>Calcium cyanide</b><br>$\text{Ca}(\text{CN})_2$                                                     | Reacts with air moisture to release HCN. If finely ground and the relative humidity of the air is >35%, this can occur fairly rapidly<br>Releases HCN slowly on contact with water or $\text{CO}_2$ , or rapidly with acids<br>Do not handle with bare hands | Nonflammable white powder or crystals                                                                                                        |
| <b>Cyanogen</b><br>(Ethane dinitrile, Prussite)<br>$(\text{CN})_2$                                     | Highly poisonous gas similar to HCN                                                                                                                                                                                                                          | Colourless flammable gas with a pungent almondlike odour, becoming acrid in higher concentrations<br>Water soluble<br>Vapour density 1.8     |
| <b>Cyanogen bromide</b><br>(Bromine cyanide)<br>$\text{CNBr}$                                          | Extremely irritating and toxic vapours<br>Contact with acids, acid fumes, water or steam can produce toxic and corrosive fumes                                                                                                                               | Transparent crystals with a penetrating odour<br>Melting point 52 °C<br>Boiling point 61 °C<br>Vapour density 3.6<br>Water soluble           |
| <b>Cyanogen chloride</b><br>(Chlorine cyanide)<br>$\text{CNCl}$                                        | Poisonous liquid or gas<br>Vapour highly irritating and very toxic                                                                                                                                                                                           | Colourless liquid with a strong irritating smell<br>Boiling point 13 °C<br>Vapour density 2.1                                                |
| <b>Potassium cyanide</b><br>$\text{KCN}$                                                               | On exposure to air, gradually decomposes to release HCN<br>Poisonous by ingestion, inhalation or skin absorption<br>Do not handle with bare hands. Strong solutions may be corrosive to the skin                                                             | Nonflammable white lumps or crystals<br>Faint odour of bitter almonds<br>Completely water soluble                                            |
| <b>Sodium cyanide</b><br>$\text{NaCN}$                                                                 | Poisonous by inhalation, ingestion or skin absorption<br>Do not handle with bare hands<br>Releases HCN slowly with water, more rapidly with acids                                                                                                            | Nonflammable white granules, fused pieces or 'eggs'<br>Odourless when dry; slight almond odour in damp air<br>Completely water soluble       |

Basic precautions include those in Table 5.36.

**Table 5.36 Basic precautions for handling gluteraldehyde**

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|                                                                                                                                                       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Use with proper local extract ventilation or, as a minimum, in a well-ventilated area                                                                 |
| Replace lids on buckets, waste bins and troughs                                                                                                       |
| Use in a manner which enables splashes, skin contact and exposure to airborne droplets or fumes to be avoided                                         |
| Use appropriate personal protective equipment, e.g. gloves, apron, visor or goggles                                                                   |
| Automation of disinfection procedures, e.g. use of automatic machines, still with a good standard of general ventilation, for disinfecting endoscopes |
| Establishment of a procedure to deal safely with any spillages                                                                                        |

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#### *(vi) Insecticides*

Insecticides may be in the form of liquid concentrates, requiring dilution in water or solvents; solutions, wettable powders, granules or pastes; or pressurized or liquefied gases. Application may be as fumigants or fogs, sprays, dust or granules. Obviously all such chemicals are toxic to varying degrees so that exposure via inhalation or ingestion, and in many cases via skin absorption, should be minimized.

The variation in toxicity of common organophosphate insecticides is exemplified in Table 5.37. The range of chlorinated hydrocarbon insecticides (Table 5.38) have, with the exception of Endrin and Isodrin, somewhat lower oral and dermal toxicities. The toxicities of a range of other insecticides, fungicides, herbicides and rodenticides are summarized in Table 5.39.

Essential precautions with insecticides are listed in Table 5.41.

#### *(vii) Irritants and corrosives*

As a class, primary irritants are the most widely encountered chemicals in industry and include inorganic acids and alkalis, halogens and halogen salts, chlorosilanes, detergents, organic solvents and organic acids and many derivatives, e.g. acid chlorides and anhydrides. In extreme cases, many are also corrosive (Table 5.4) and, in the case of organic compounds, possibly flammable. The skin, eyes and mucous membranes are at greatest risk although the respiratory tract is affected if the materials become airborne as dusts or aerosols, or if gaseous or volatile, e.g. halogens and inorganic anhydrous acids (Tables 5.42 and 5.43). Table 5.44 lists the properties of selected organic acids.

Typical precautions for work with irritant and corrosive chemicals are listed in Table 5.45.

#### *(viii) Mercury*

Mercury is used in the manufacture of thermometers, barometers and switchgear, and in the production of amalgams with copper, tin, silver and gold, and of solders. A major use in the chemical industry is in the production of a host of mercury compounds and in mercury cells for the generation of chlorine. Mercury has a significant vapour pressure at ambient temperature and is a cumulative poison.

The liquid attacks many metals, including aluminium, gold, copper and brass. Splashes break up into very small, mobile droplets, making clean-up of spillages difficult.

Mercury should not be left exposed in a laboratory. Reservoirs etc. should be covered with a layer of water or oil and, if practicable, the neck of the vessel plugged. The risk is increased by



**Table 5.37 Organophosphate insecticides (see also Table 5.12)**

| <i>Insecticide</i>                                                                 | <i>Oral LD<sub>50</sub></i><br>(mg/kg) | <i>Dermal LD<sub>50</sub></i><br>(mg/kg) | <i>UK OES</i><br><i>8 hr TWA value</i><br>(mg/m <sup>3</sup> ) |
|------------------------------------------------------------------------------------|----------------------------------------|------------------------------------------|----------------------------------------------------------------|
| Abate                                                                              | 8600–13 000                            | 4000                                     | —                                                              |
| Azinphosmethyl (Guthion)                                                           | 11–13                                  | 220                                      | 0.2 SK                                                         |
| Azodrin                                                                            | 17.5–20                                | 112–126                                  | —                                                              |
| Bidrin                                                                             | 22                                     | 225                                      | —                                                              |
| Carbophenothion                                                                    | 10–30                                  | 27–54                                    | —                                                              |
| Chlorthion                                                                         | 890–980                                | 4100–4500                                | —                                                              |
| Ciodrin                                                                            | 125                                    | 385                                      | —                                                              |
| Coumaphos (Co-Ral)                                                                 | 15.5–41                                | 860                                      | —                                                              |
| Demeton (Systox)                                                                   | 2.5–6.2                                | 8.2–14                                   | —                                                              |
| Diazinon                                                                           | 76–108                                 | 455–900                                  | —                                                              |
| Dicapthon                                                                          | 330–400                                | 790–1250                                 | —                                                              |
| Dimethyldichlorovinyl Phosphate (DDVP)                                             | 56–80                                  | 75–107                                   | —                                                              |
| Dimethoate                                                                         | 215                                    | 400–610                                  | —                                                              |
| Dioxathion (Delnav)                                                                | 23–43                                  | 63–235                                   | 0.2 SK                                                         |
| Disulfoton (Di-Syston)                                                             | 2.3–6.8                                | 6–15                                     | 0.1                                                            |
| <i>O</i> -ethyl- <i>O</i> - <i>p</i> -nitrophenyl Phenyl<br>Phosphonothioate (EPN) | 7.7–36                                 | 25–230                                   | —                                                              |
| Ethion                                                                             | 27–65                                  | 62–245                                   | 8 SK                                                           |
| Fenthion (Baytex)                                                                  | 215–245                                | 330                                      | —                                                              |
| Malathion                                                                          | 1000–1375                              | 4444                                     | 10 SK                                                          |
| Methyl Parathion                                                                   | 14–24                                  | 67                                       | 0.2 SK                                                         |
| Methyl Trithion                                                                    | 98–120                                 | 190–215                                  | —                                                              |
| Naled                                                                              | 250                                    | 800                                      | 3 SK                                                           |
| Nemacide                                                                           | 270                                    | —                                        | —                                                              |
| NPD                                                                                | —                                      | 1800–2100                                | —                                                              |
| Octamethyl Pyrophosphoramidate (Schradan)                                          | 9.1–42                                 | 15–44                                    | —                                                              |
| Parathion                                                                          | 3.6–13                                 | 6.8–21                                   | 0.1 SK                                                         |
| Phorate (Thimet)                                                                   | 1.1–2.3                                | 2.5–6.2                                  | 0.05 SK                                                        |
| Phosdrin (Mevinphos)                                                               | 3.7–6.1                                | 4.2–4.7                                  | 0.1 SK                                                         |
| Phosphamidon                                                                       | 23.5                                   | 107–143                                  | —                                                              |
| Ronnel (Korlan)                                                                    | 1250–2630                              | 5000                                     | 10                                                             |
| Ruelene                                                                            | 460–635                                | —                                        | —                                                              |
| Sulfotep, Tetraethyl Dithiopyrophosphate (TEDP)                                    | —                                      | —                                        | 0.2 SK                                                         |
| Tetraethyl Pyrophosphate (TEPP)                                                    | 1.05                                   | 2.4                                      | 0.05 SK                                                        |
| Trichlorfon (Dipterex)                                                             | 560–630                                | 2000                                     | —                                                              |

SK Can be absorbed through skin.

The LD<sub>50</sub> varies according to species of animal, sex, age and health.

heating, e.g. due to spillage on a hot surface; no glass blowing should therefore be done on mercury-contaminated glass.

Care is essential to avoid spillages. A fine capillary tube connected to a filter flask and filter pump should be used immediately to collect any spillage. Surfaces, e.g. floors, contaminated by minute mercury droplets should be treated with sulphur or zinc dust, or by use of a commercial clean-up kit.

Rooms in which mercury is regularly exposed should be subjected to routine atmospheric monitoring. Personnel in such rooms should receive periodic medical examinations.

For routine laboratory precautions refer to Table 5.40.



**Table 5.38 Chlorinated hydrocarbon insecticides (see also Table 5.12)**

| <i>Insecticide</i>              | <i>Oral LD<sub>50</sub></i><br>(mg/kg) | <i>Dermal LD<sub>50</sub></i><br>(mg/kg) | <i>UK OES</i><br><i>8 hr TWA value</i><br>(mg/m <sup>3</sup> ) |
|---------------------------------|----------------------------------------|------------------------------------------|----------------------------------------------------------------|
| Aldrin                          | 39–60                                  | 98                                       | 0.25 SK                                                        |
| Benzene Hexachloride (BHC)      | 1250                                   | —                                        | —                                                              |
| Chlordane                       | 335–430                                | 690–840                                  | 0.5 SK                                                         |
| Chlorobenzilate                 | 1040–1220                              | <5000                                    | —                                                              |
| DDT                             | 113–118                                | 2510                                     | 1.0                                                            |
| Dichloropropane-Dichloropropene | 140                                    | 2100                                     | —                                                              |
| Dicofol (Kelthane)              | 1000–1100                              | 1000–1230                                | —                                                              |
| Dieldrin                        | 46                                     | 60–90                                    | 0.25 SK                                                        |
| Dilan                           | —                                      | 5900–6900                                | —                                                              |
| Endosulfan (Thiodan)            | 18–43                                  | 74–130                                   | —                                                              |
| Endrin                          | 7.5–17.8                               | 15–18                                    | 0.1 SK                                                         |
| Ethylene Dibromide              | 117–146                                | 300                                      | —                                                              |
| Ethylene Dichloride             | 770                                    | 3890                                     | —                                                              |
| Heptachlor                      | 100–162                                | 195–250                                  | 0.5 SK                                                         |
| Isodrin                         | 7.0–15.5                               | 23–35                                    | —                                                              |
| Kepone                          | 125                                    | <2000                                    | —                                                              |
| Lindane                         | 88–91                                  | 900–1000                                 | 0.5 SK                                                         |
| Methoxychlor                    | 5000                                   | —                                        | 10                                                             |
| Mirex                           | 600–740                                | 2000                                     | —                                                              |
| Para-Dichlorobenzene            | 1000                                   | —                                        | —                                                              |
| Perthane                        | 4000                                   | —                                        | —                                                              |
| Strobane                        | 200                                    | 5000                                     | —                                                              |
| TDE                             | 4000                                   | 4000                                     | —                                                              |
| Telone                          | 200–500                                | —                                        | —                                                              |
| Toxaphene                       | 80–90                                  | 780–1075                                 | —                                                              |

SK can be absorbed through skin.

The LD<sub>50</sub> varies according to species of animal, sex, age and health.

### *(ix) Mineral oil lubricants*

Mineral oils, i.e. oils derived from petroleum, are widely used as lubricants, cutting oils, soluble oil coolants etc.

They have very low acute toxicities, i.e. oral LD<sub>50</sub> values of around 10 g/kg. They are not absorbed via the skin and are insufficiently volatile to produce harmful vapours at room temperature. Additives are used in small quantities for specific properties but these do not normally affect the health and safety characteristics. Dermatitis may be caused by repeated or prolonged contact of mineral oils with the skin. Such contact with higher boiling fractions over many years can result in warty growths which may become malignant, e.g. on the scrotum following contamination of the front of overalls, possibly from oily rags in trouser pockets. Carcinogenic activity is reduced by solvent refining of the base stocks but can increase with use. Oil mists at concentrations normally encountered are primarily a nuisance, but very high concentrations could, on inhalation, cause irritation of the lungs leading to pneumonia. Because of the carcinogenic potential the atmospheric concentration should be controlled below 5 mg/m<sup>3</sup> as an 8 hr TWA concentration and 10 mg/m<sup>3</sup> as a 10 min STEL concentration. General recommendations for precautions with mineral oils are summarized in Table 5.46.

**Table 5.39 Insecticides, rodenticides, fungicides and herbicides (see also Table 5.12)**

| <i>Substance</i>     | <i>Oral LD<sub>50</sub></i><br>(mg/kg)               | <i>Dermal LD<sub>50</sub></i><br>(mg/kg) | <i>UK OES 8hr TWA value</i><br>(mg/m <sup>3</sup> ) |
|----------------------|------------------------------------------------------|------------------------------------------|-----------------------------------------------------|
| <b>Insecticides</b>  |                                                      |                                          |                                                     |
| Binapacryl           | 58–63                                                | 720–810                                  | —                                                   |
| Calcium Arsenate     | 298                                                  | 2400                                     | —                                                   |
| Carbaryl             | 500–850                                              | 4000                                     | 5                                                   |
| Cryolite             | 200                                                  | —                                        | —                                                   |
| DN-111               | 330                                                  | 1000                                     | —                                                   |
| Lead Arsenate        | —                                                    | 2400                                     | 0.15                                                |
| Metaldehyde          | 1000                                                 | —                                        | —                                                   |
| Morestan             | 1800                                                 | —                                        | —                                                   |
| Naphthalene          | 2400                                                 | 2500                                     | 50                                                  |
| Nicotine Sulphate    | 83                                                   | 285                                      | —                                                   |
| Ovex                 | 2050                                                 | —                                        | —                                                   |
| Paris Green          | 100                                                  | 2400                                     | —                                                   |
| Pyrethrum            | 1500                                                 | 1800                                     | —                                                   |
| Rotenone             | 50–75                                                | 940                                      | 5                                                   |
| Ryania               | 1200                                                 | 4000                                     | —                                                   |
| Tetradifon           | 14 700                                               | 10 000                                   | —                                                   |
| Zineb                | 5200                                                 | —                                        | —                                                   |
| <b>Rodenticides</b>  |                                                      |                                          |                                                     |
| Sodium Fluoroacetate | —                                                    | —                                        | 0.05 SK                                             |
| Strychnine           | —                                                    | —                                        | 0.15                                                |
| Thallium Sulphate    | —                                                    | —                                        | 0.1 as TI, SK                                       |
| Warfarin             | —                                                    | —                                        | 0.1                                                 |
| <b>Fungicides</b>    |                                                      |                                          |                                                     |
| Ferbam               | 17 000                                               | —                                        | 10                                                  |
| Formaldehyde         | —                                                    | —                                        | 2.5 MEL                                             |
| Organic Mercurials   | —                                                    | —                                        | 0.01                                                |
| Maneb                | 7500                                                 | —                                        | —                                                   |
| Nabam                | 395                                                  | —                                        | —                                                   |
| Pentachlorophenol    | —                                                    | —                                        | 0.5 SK                                              |
| Ziram                | 1400                                                 | —                                        | —                                                   |
| <b>Herbicides</b>    |                                                      |                                          |                                                     |
| 2,4-D                | 375–700<br>(different<br>acids, salts<br>and esters) | —                                        | 10                                                  |
| 2,4,5,-T             | 481–500<br>(different acids<br>and esters)           | —                                        | 10                                                  |
| Dinitrocresol (DNOC) | 30                                                   | —                                        | 0.2 SK                                              |

SK Can be absorbed through skin.

The LD<sub>50</sub> varies according to species of animal, sex, age and health.*(x) Metalworking fluids*

Metalworking fluids contain mineral oils (refer to p. 80) or synthetic lubricants; they are used neat or in admixture with water. They may contain small amounts of biocides, stabilizers, emulsifiers, corrosion inhibitors, fragrances and extreme pressure additives. The formulations render them suitable for application to metal being worked, generally from a recirculatory system, to provide lubrication, corrosion protection, swarf removal and cooling of the tool and machined surface.

**Table 5.40 Routine laboratory precautions with mercury**


---

|                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------|
| Avoid the use of mercury, if possible                                                                                                          |
| Store in airtight containers or under water or liquid paraffin                                                                                 |
| Handle over a suitable tray near to the apparatus in use                                                                                       |
| Avoid wearing rings. Wear gloves. Wash the hands and gloves after handling mercury                                                             |
| Use catchpots under apparatus containing mercury                                                                                               |
| Use only apparatus strong enough to withstand the considerable force which may arise due to movements of mercury (e.g. rigid pvc or polythene) |
| Clean up all spillages immediately and check for pockets (e.g. in cracks and crevices) by monitoring                                           |
| Decontaminate equipment such as vacuum pumps and glassware prior to service/maintenance                                                        |

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**Table 5.41 Guidance on safety with pesticides**


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|                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Approval</b>                        | In the UK only approved pesticides may be supplied and used<br>Each product has an approval number and conditions of use                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Storage requirements</b>            | Suitable siting<br>Adequate capacity and construction<br>Designed to hold spillage<br>Properly lit and ventilated<br>Fire- and frost-resistant<br>Designed so that containers can be safely stacked and moved<br>Clearly marked<br>Kept locked except when in use                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Competence</b>                      | Every user must be competent (Certificate of Competence required in UK)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Information</b>                     | Workers must be supplied with sufficient information and guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Evaluation of possible problems</b> | Product selection<br>How to comply with the conditions of approval<br>Selection of protective clothing<br>How to avoid spray drift<br>How to avoid environmental damage<br>Need to warn neighbours and others who may be affected etc.                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Training requirements</b>           | Pesticide legislation<br>Decisions on whether a pesticide has to be used<br>Selection of appropriate pesticide<br>Interpretation of labels and codes of practice<br>Hazards and risks to human health/the environment<br>Selection and use of engineering controls and protective clothing<br>Calibration and safe operation of application equipment<br>Safe storage and disposal of pesticides<br>Emergency action in case of poisoning or contamination<br>How to contain and deal with accidental spillage<br>Constraints imposed by weather or other factors<br>Appropriate record keeping<br>Need for exposure monitoring/health surveillance |
| <b>Exposure control</b>                | Use engineering/technical means, e.g.<br>Low-level filling bowls<br>Suction probes<br>Closed handling systems<br>Soluble packs<br>In-cab electronic sprayer controls<br>Hydraulic boom-folding<br>(These measures should be used in preference to protective clothing)                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Disposal</b>                        | Minimize disposal requirements by careful estimation of needs and correct measurement<br>Dispose of dilute pesticides by using as a spray, in accordance with 'approval', in a safe/approved area<br>Concentrated, unused pesticides should be stored, returned or disposed of as toxic waste                                                                                                                                                                                                                                                                                                                                                       |

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**Table 5.42 Halogens**

| <i>Halogen</i>              | <i>Melting point<br/>( °C)</i> | <i>Boiling point<br/>( °C)</i> | <i>Vapour density<br/>(air = 1.0)</i> | <i>Threshold limit<br/>value (ppm)</i> | <i>Reactivity and<br/>oxidizing strength</i> | <i>Appearance and<br/>state at 21 °C</i>                       | <i>Colour of<br/>gas/vapour</i>  |
|-----------------------------|--------------------------------|--------------------------------|---------------------------------------|----------------------------------------|----------------------------------------------|----------------------------------------------------------------|----------------------------------|
| Fluorine (F <sub>2</sub> )  | −217                           | −188                           | 1.3                                   | 0.1                                    | Extremely active                             | Pale yellow gas                                                | Pale yellow                      |
| Chlorine (Cl <sub>2</sub> ) | −101                           | −34                            | 2.5                                   | 1.0                                    | Very active                                  | Greenish-yellow<br>gas. Amber<br>liquid at 5.8<br>bar pressure | Greenish-yellow                  |
| Bromine (Br <sub>2</sub> )  | −6.6                           | 59                             | 5.5                                   | 0.1                                    | Active                                       | Dark red liquid                                                | Dark red<br>to reddish-<br>brown |
| Iodine (I <sub>2</sub> )    | 113                            | 185 <sup>(1)</sup>             | 8.6                                   | 0.1                                    | Least active                                 | Bluish-black<br>lustrous solid                                 | Violet                           |

<sup>(1)</sup> Readily sublimes at lower temperatures.

Table 5.43 Common anhydrous acids

| <i>Chemical</i>                                                  | <i>Melting point<br/>(°C)</i> | <i>Boiling point<br/>(°C)</i> | <i>Typical cylinder<br/>pressure at 21°C<br/>(bar)</i> | <i>Vapour<br/>density<br/>(air = 1.0)</i> | <i>Properties</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------|-------------------------------|-------------------------------|--------------------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Hydrogen bromide</b><br>(Anhydrous hydrobromic acid)<br>HBr   | −86                           | −69                           | 22                                                     | 2.8                                       | Colourless, corrosive nonflammable gas with an acrid odour<br>Highly irritating to eyes, skin and mucous membranes<br>Fumes in moist air, producing clouds with a sour taste<br>Freely soluble in water                                                                                                                                                                                                                                                                                                                                                          |
| <b>Hydrogen chloride</b><br>(Anhydrous hydrochloric acid)<br>HCl | −111                          | −83                           | 42.4                                                   | 1.3                                       | Colourless, corrosive nonflammable gas with a pungent odour<br>Considered somewhat more dehydrating and more corrosive than the mists and vapours of hydrochloric acid<br>Fumes in air<br>Very water soluble                                                                                                                                                                                                                                                                                                                                                     |
| <b>Hydrogen fluoride</b><br>(Anhydrous hydrofluoric acid)<br>HF  | −83                           | 19                            | 0.069                                                  | 0.7                                       | Colourless, corrosive nonflammable liquid or gas with a penetrating odour<br>Highly irritating and poisonous<br>Very soluble in water. Liquid liberates heat as it dissolves in water. The entrapment of water in an anhydrous hydrogen fluoride cylinder can cause rapid generation of heat and pressure which can lead to an explosion. Containers should never be heated to >52°C. A liquid hydrogen fluoride spill area should not be entered unless protective clothing (impervious to the compound) and a self-contained gas mask are worn<br>Fumes in air |
| <b>Hydrogen iodide</b><br>(Anhydrous hydriodic acid)<br>HI       | −51                           | −35                           |                                                        |                                           | Colourless, corrosive nonflammable gas with an acrid odour<br>Highly irritating to eyes, skin and mucous membranes<br>Attacks natural rubber<br>Decomposed by light<br>Extremely soluble in water<br>Fumes in moist air                                                                                                                                                                                                                                                                                                                                          |

Hand dispensing is also used but on most modern machines application is by a continuous jet, spray or mist.

Skin contact with metalworking fluids may cause skin irritation or a contact irritant dermatitis. Contact with neat oils may cause folliculitis (oil acne). Contact with some aqueous-mix fluids may, depending upon the additives, e.g. biocides, cause an allergic contact dermatitis. Formerly the use of unrefined mineral oils posed a risk of skin cancer.

The fumes and mist from metalworking fluids may cause irritation of the eyes, nose and throat.

**Table 5.44 Common organic acids**

| <i>Acid</i>                                                                         | <i>Flash point<br/>( C )</i> | <i>Ignition<br/>temperature<br/>( C )</i> | <i>Specific<br/>gravity<br/>(water = 1.0)</i> | <i>Vapour<br/>density<br/>(air = 1.0)</i> | <i>Boiling<br/>point<br/>( C )</i> | <i>Properties</i>                                                                                                                                                                                                                                                                               |
|-------------------------------------------------------------------------------------|------------------------------|-------------------------------------------|-----------------------------------------------|-------------------------------------------|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Acetic acid</b> (glacial)<br>(Ethanoic acid)<br>$\text{CH}_3\text{COOH}$         | 40                           | 426                                       | 1.05                                          | 2.07                                      | 118                                | Clear, colourless water-soluble mobile liquid<br>Strong vinegar odour<br>Lower explosive limit 4%<br>Glacial acetic is a concentration of acetic acid >99%<br>Expands on freezing into an icelike solid at 16.6 C; can break container                                                          |
| <b>Butyric acid</b><br>(Butanoic acid)<br>$\text{CH}_3(\text{CH}_2)_2\text{COOH}$   | 72                           | 452                                       | 0.96                                          | 3.04                                      | 163                                | Colourless water-soluble oily liquid with strong odour                                                                                                                                                                                                                                          |
| <b>Formic acid</b><br>$\text{HCOOH}$                                                | 69                           | 601                                       | 1.22                                          | 1.59                                      | 100                                | Colourless water-soluble fuming liquid with pungent penetrating odour<br>Glacial acid freezes at 8 C<br>Decomposes slowly in storage, liberating carbon monoxide<br>Sufficient gas pressure can accumulate in tightly sealed tank to cause rupture or leakage<br>Common concentrations all >90% |
| <b>Propionic acid</b><br>(Methylacetic acid)<br>$\text{CH}_3\text{CH}_2\text{COOH}$ | 54                           | 512                                       | 0.99                                          | 2.56                                      | 141                                | Colourless liquid with slightly pungent and rancid odour                                                                                                                                                                                                                                        |

Breathing difficulties, i.e. bronchitis or asthma, arising from sensitization to bacterial contamination or additive chemicals, have been reported.

The formation of nitrosamines, e.g. *n*-nitrosodiethanolamine, which are possible human carcinogens, can occur in synthetic or semi-synthetic fluids which contain a nitrite salt and diethanolamine or triethanolamine.

Basic precautions include those in Table 5.47.

#### (xi) *Painting*

Industrial painters may suffer adverse health effects from over exposure to paint by skin contact or accidental ingestion, from excessive inhalation of paint aerosol, solvent vapour, or of dust in the case of electrostatically-applied powder coatings (e.g. polyesters containing triglycidyl isocyanurate), or from exposure to thermal degradation products from heated paint or plastic coatings (Table 5.48).

Precautions for paintwork are summarized in Table 5.49.

Table 5.45 Precautions in handling primary irritants/corrosives

|                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Avoid contact</b>       | <p>Use in most dilute form practicable</p> <p>Minimize opportunity for contact and time of contact</p> <p>Select appropriate constructional materials (flexible hoses)</p> <p>Allow for clearance of blockage (e.g. steaming)</p> <p><i>Containment</i></p> <p>Avoid open tanks, even if only loose lids practicable</p> <p>Provide barriers</p> <p>Use handling technique that avoids airborne contamination</p> <p><i>Mechanical handling</i></p> <p>In-plant transfer preferably by pipeline</p> <p>Alternatively use special vessels, e.g. lined drums, or continuous arrangements for enclosed transfer</p> <p>Drums should be emptied using pumps/forklift trucks etc.</p> <p>Avoid manual tipping</p> <p>Provide warning notices to identify containers and areas where corrosive chemicals are in use, and instructions regarding necessary protection, particularly eye protection areas</p> <p>Identify vessels, pumps and pipelines (e.g. colour coding, numbering)</p> <p><i>Spillage</i></p> <p>Retain with bunds etc.</p> <p>Neutralize or mop up immediately</p> <p>Maintain supplies of neutralizing chemicals, e.g. soda ash</p> <p>Provide hosing-down facilities where appropriate</p> <p>Minimize joints, particularly drain and sample points, valves/pipe joints, flanges over access ways</p> <p>Avoid flexible hoses where possible; otherwise secure, shield and maintain</p> <p>Shield glass sections</p> <p>Provide separate FULL and EMPTY storage areas</p> <p>Use road or rail tanker for bulk transfer; if small containers are used, they should be of correct design (free space, pressure, corrosion)</p> <p>Label containers according to hazard, precautions, first aid</p> <p>Segregate incompatible materials</p> <p>Maintain good housekeeping</p> |
| <b>Personal protection</b> | <p>Depending on scale of operation, use impervious rubber gloves, eye protection (glasses/goggles/face shield), rubber aprons, boots, armlets, protective suits</p> <p>Provide respiratory protection against gases/dusts/fumes</p> <p>Provide shower and eyewash facilities</p> <p>Use protective/barrier creams and skin reconditioning creams</p> <p>Maintain high standard of personal hygiene</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>First aid measures</b>  | <p>Investigate all complaints</p> <p>In the case of injury, obtain medical attention rapidly</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Emergency measures</b>  | <p>Copiously flush eyes with water for up to 15 min, and skin with water and soap – <i>except</i> in the case of substances such as quicklime whose reaction with water is exothermic (1 g generates &gt;18 kcal), titanium or tin tetrachloride, both of which rapidly hydrolyze to form hydrochloric acid</p> <p>Therapeutic measures for specific chemicals include:</p> <p><i>White phosphorus.</i> This element burns in air and can produce severe thermal and chemical burns. It may reignite on drying. After washing, rapid but brief treatment with copper sulphate (to avoid systemic absorption and copper poisoning) is used to convert the phosphorus to copper phosphide which is then removed</p> <p><i>Hydrogen fluoride.</i> This can form painful but delayed necrosis. Treat with calcium gluconate locally and monitoring of serum calcium levels, with administration of calcium where necessary</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

**Table 5.46 General precautions with mineral oils**


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Avoid all unnecessary contact with mineral and synthetic oils, e.g. by carefully designed work practices  
 Avoid extreme exposure to oil mist or vapours  
 When used as a machine coolant:

substitute by oil-in-water emulsions (suds) or by nitrite-free synthetic coolants;  
 use of an adequate flow of cooling to minimize 'fuming';  
 provide l.e.v.;  
 provide and use enclosures and splash guards wherever practicable;  
 regularly change coolant and machine system cleaning.  
 with solutions or emulsions control concentration in use.

For machine operation, use of protective clothing, e.g. impervious aprons with detachable absorbent fronts (see also below).  
 Protective gloves may be helpful if they can be kept clean inside (porous gloves may prolong exposure)  
 Impervious elasticated armlets may be appropriate  
 Provide a readily available supply of disposable rags  
 Do not carry used rags in overall or trouser pockets  
 Wear goggles if eye contact is likely

Wear clean work clothes

Consider short-sleeved overalls for workers using metal cutting fluids (avoids skin friction from cuffs saturated with oil and holding particles of swarf)

Dry-clean oily overalls

Change underclothes that become wet with oils, and wash thoroughly

Wash skin thoroughly to remove all traces of oil

Avoid strong soaps, detergents, abrasive skin cleansers

Do not use paraffin (kerosene), petrol (gasoline), chlorinated hydrocarbons or proprietary solvents to cleanse skin

Use barrier cream before work and after washing hands (different barrier creams protect against different oils – a cream intended for soluble oil does not protect against straight oils)

Use skin reconditioning cream after washing hands at end of shift

See that all cuts and scratches receive prompt medical attention

Seek medical advice as soon as an irritation or other skin abnormality appears

Maintain a high standard of housekeeping – a clean workplace encourages clean work practices

Encourage self-checks and provide the necessary information – e.g. leaflet MS(B)5 available free from HSE

Use warning notices, placards etc. to promote good personal hygiene and good work practices

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**Table 5.47 Basic precautions for metalworking fluids**


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Design, maintain and operate machine tools to minimize fumes and mist generation, splashing and skin contamination

Provide local exhaust ventilation as appropriate

Control fluid quality during use, involving checks on correct dilution and make-up, concentration and freedom from contamination in service, regular cleaning and fluid changing

Provide and use appropriate personal protective equipment

A high standard of personal hygiene

Regular skin inspections, e.g. at a frequency of once per month; monitoring of any respiratory problems by simultaneous enquiries and completion of an annual questionnaire

Prohibit air lines for blowing clean components

Prohibit eating, drinking or smoking near machines

Remove swarf and fines from, and prevent hydraulic oil leakage into, recirculated fluid

Avoid the use of water-mix synthetic fluids containing nitrites if there is a technologically effective alternative.

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**Table 5.48 Potential pollutants from heated paints or plastic coatings**

| <i>Elements in resin</i>                                     | <i>Chemical classification of resin</i>                                                                                                                                                                         | <i>Possible products of pyrolysis</i>                                                                                                                                                                         |
|--------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Carbon, hydrogen and possibly oxygen                         | Resin and derivatives<br>Natural drying oils<br>Cellulose derivatives<br>Alkyd resins<br>Epoxy resins (uncured)<br>Phenol-formaldehyde resins<br>Polystyrene<br>Acrylic resins<br>Natural and synthetic rubbers | Carbon monoxide<br>Aldehydes (particularly formaldehyde, acrolein and unsaturated aldehydes)<br>Carboxylic acids<br>Phenols<br>Unsaturated hydrocarbons<br>Monomers, e.g. from polystyrene and acrylic resins |
| Carbon, hydrogen, nitrogen and possibly oxygen               | Amine-cured epoxy resins<br>Melamine resins<br>Urea-formaldehyde resins<br>Polyvinyl pyridine or pyrrolidine<br>Polyamides<br>Isocyanate (polyurethanes)<br>Nitrocellulose derivatives                          | As above, but also various nitrogen-containing compounds, including nitrogen oxides, hydrogen cyanide, isocyanates                                                                                            |
| Carbon, hydrogen and possibly halogens, sulphur and nitrogen | Polyvinyl halides<br>Halogenated rubbers<br>PTFE and other fluorinated polymers<br>Thiourea derivatives<br>Sulphonamide resins<br>Sulphochlorinated compounds                                                   | As above, but also halogenated compounds. These may be particularly toxic when fluorine is present<br>Hydrogen halides<br>Carbonyl chloride (phosgene)<br>Hydrogen sulphide<br>Sulphur dioxide                |

**Table 5.49 Precautions in preparation and paintwork**

Information (i.e. at least a safety data sheet and comprehensive container label) and training related to the hazards in the handling and use of the range of chemicals.

Use where practicable of less harmful chemicals, e.g. water-based paints.

Provision and use of appropriate health surveillance, e.g. for signs of dermatitis, asthma, effects of specific solvent exposures.

Full use of any spray booth, enclosure, exhaust ventilation or dilution systems, and automatic handling equipment. (The efficiency of all local exhaust ventilation and other control systems should be maintained, and checked by testing.)

Where appropriate, atmospheric monitoring of airborne pollution levels.

Full use, where appropriate, of ventilation, e.g. by opening doors, windows.

Prompt attention to any damaged or malfunctioning equipment, e.g. general ventilation.

Replacement of lids on containers.

Correct disposal of paint, thinner, impregnated rags.

Use, where appropriate, of a properly-fitting respirator with correct filter or air-fed equipment.

Use of a vacuum cleaner or damping techniques to minimize dust generation.

Avoidance of the use of unauthorised thinners for paint dilution, surface preparation or cleaning of spray guns/brushes/rollers.

Avoidance of skin contact and ingestion of chemicals by:

Use of protective clothing and eye protection.

Use of barrier cream and skin conditioning cream.

Removal of jewellery etc. which can trap chemicals in contact with the skin.

Avoidance of excessive skin contact with solvents, e.g. when cleaning brush, spray guns; not washing hands in solvents.

Avoidance of eating, drinking or smoking while painting.

A good standard of personal hygiene, i.e. washing hands before eating, and showering or bathing at the end of work.

Maintaining overalls and respiratory protection in a clean state.

Leaving protective clothing at work.

*(xii) Perchloroethylene (tetrachloroethene, tetrachloroethylene)*

Perchloroethylene is a clear, dense, non-flammable volatile chlorinated solvent. It is widely used for dry cleaning; small quantities are used in adhesives and cleaning agents. It is miscible with organic solvents but only slightly soluble in water. Relevant physical properties are given in Table 5.50.

**Table 5.50 Physical properties of perchloroethylene**

|                                |                               |
|--------------------------------|-------------------------------|
| Boiling point                  | 121 C                         |
| Saturated vapour concentration | $1.5 \times 10^4$ ppm at 20 C |
| Specific gravity               | 1.623 at 20 C                 |
| Vapour density (air = 1)       | 5.83 at 74 C                  |
| Solubility in water            | 0.015% w/w at 25 C            |

This solvent has an ethereal odour with a detection threshold between 5 and 80 ppm. It can be absorbed orally, by inhalation and through the skin, and small amounts of the compound can be detected in the breath of humans several days after exposure. Overexposure by inhalation can cause central nervous system (CNS) depression – characterized by dizziness, light-headedness, inebriation and difficulty in walking – and liver damage. Minimal CNS effects occur at exposures of about 100 ppm. Chronic exposure has resulted in peripheral neuropathy. Ingestion of large doses can cause internal irritation, nausea, vomiting and diarrhoea; it can cause drowsiness or unconsciousness. Contact with the skin will result in degreasing, resulting in mild irritation possibly leading to cracking and secondary infection; in extreme cases dermatitis may occur.

Eye contact with vapour above 100 ppm may cause irritation. Liquid splashes produce irritation.

Studies on the carcinogenicity are inconclusive but IARC classify tetrachloroethylene as a probable human carcinogen (Class 2A – see Table 5.17).

Thermal degradation in contact with flame or red hot surfaces will produce highly-toxic gases, e.g. acid chlorides and phosgene. Reaction with freshly-galvanized surfaces may produce dichloroacetylene, which is also highly toxic.

The long-term OES is 50 ppm (8 hr TWA), set to protect against CNS effects, which will also protect against liver or kidney damage and irritation. The short-term OES is 1000 ppm (15 minute reference period) to minimize exposures at irritant levels.

Tetrachloroethylene has been detected in the food chain as a contaminant: its volatility prevents significant bioaccumulation but some transfer to aquatic sediments is possible. At low concentrations it is slowly degraded under anaerobic conditions.

The precautions for the use of perchloroethylene correspond with those for trichloroethylene (Table 5.52). The dry cleaning process, and its safety measures comprise:

- cleaning in hot solvent in sealed machines;
- drying with hot air (after centrifugal removal of liquid solvent) which passes over a lint filter then cooled to condense solvent;
- deodorization to remove last traces of solvent with fresh air with venting to atmosphere;
- solvent recovery by distillation. Normal measures for solvent control use activated charcoal absorption filters often as disposable cartridges. Still residues are usually removed manually from each machine at least once per week, or in some machines they are pumped directly to a waste storage vessel, often a lidded metal container located outside the building.

**Table 5.51 Physical properties of trichloroethylene**

|                                |                                |
|--------------------------------|--------------------------------|
| Boiling point                  | 87 °C                          |
| Saturated vapour concentration | $7.9 \times 10^4$ ppm at 20 °C |
| Specific gravity               | 1.464 at 20 °C                 |
| Vapour density (air = 1)       | 4.54                           |
| Solubility in water            | 0.11% w/w at 25 °C             |

**Table 5.52 General safety precautions with trichloroethylene and tetrachloroethylene****Do not**

Store liquid in buckets or other open storage vessels.  
 Lean into any vessel containing liquid or vapour.  
 Use in any location which is not well ventilated, but avoid extraneous draughts.  
 Enter any confined space, e.g. any tanks or pits, except in accordance with a permit-to-work system.

**Do**

Store in the open air if possible, or at least in a well-ventilated area which is not below ground level.  
 Provide and maintain efficient local exhaust ventilation, if enclosed plant cannot be used.  
 Avoid smoking in proximity to any open system.  
 Replace lids on any open-topped tanks.  
 Wear eye protection if there is any risk of splashing.  
 Avoid contact with the skin. If hand contact is likely, wear PVC gloves.  
 Avoid contact of liquid or vapour with naked flames or red-hot surfaces.  
 In vapour degreaser operation, do:  
   control vapour at the specified level within the tank;  
   employ effective l.e.v. and prevent draughts in the workroom, e.g. by suitable screening;  
   avoid overheating of solvent and uncontrolled vaporization, including prevention by the use of appropriate thermostats;  
   lower and raise work loads slowly, to minimize vapour displacement;  
   carefully position, or drain, hollow articles.  
 When cleaning plant, if plant is within a pit, do:  
   ensure ventilation draws air from the bottom of the pit;  
   distil off vapour in accordance with specific operating instructions;  
   allow any liquid to cool to ambient temperature before drawing off into a suitable receptacle;  
   remove sludge by raking through sump door, after allowing several hours for ventilation;  
   restrict any entry, in accordance with the Confined Space Regulations 1997.

*(xiii) Trichloroethylene (trichloroethene)*

Trichloroethylene is a colourless non-flammable chlorinated hydrocarbon liquid. It is mainly used for degreasing of metals in the engineering and electrical appliance industries; other outlets are as a solvent in inks, in dry-cleaning, in varnishes and adhesives, and as a solvent in the extraction of fats and oils. Relevant physical properties are given in Table 5.51.

The solvent has a sweetish odour similar to chloroform detectable at about 30 ppm. It is primarily a depressant of the central nervous system (CNS). Significant impairment of performance in behavioural tests and some CNS effects have occurred at 1000 ppm but not at 300 ppm; prenarctic symptoms have occurred at mean levels of 200 ppm to 300 ppm.

Direct eye contact with liquid produces injury, generally transient, to the corneal epithelium. The liquid is mildly irritating to the skin due to the degreasing effect; repeated contact may cause dermatitis. Ingestion of substantial quantities of liquid can damage the mucous membranes, and produce acute effects ranging from mild discomfort to profound anaesthesia.

Evidence to indicate that exposure to trichloroethylene is associated with an increased incidence of cancer in man or in adverse effects in the offspring of women workers exposed to the compound

is confused but IARC classify trichloroethylene as a probable human carcinogen, Class 2A (see Table 5.17).

Decomposition of trichloroethylene can occur upon contact with naked flames, red-hot surfaces, hot elements of electric heaters, or intense UV light with the generation of acidic and highly-toxic products. The presence of reactive contaminants, e.g. acids, strong alkalis, highly-reactive metals, may also result in decomposition to similar products.

The Occupational Exposure Standards imposed for trichloroethylene are Maximum Exposure Limits of 100 ppm (8 hr TWA) and 150 ppm (15 minute reference period). A skin notation 'Sk' is applicable because of the potential for skin absorption. Because of its volatility, trichloroethylene is not recommended for cold cleaning; it is normally used in partially enclosed vapour degreasing equipment provided with local exhaust ventilation.

Typical precautions with trichloroethylene are summarized in Table 5.52. An important factor is that the vapours are much heavier than air; they will therefore spread and may accumulate at low levels, particularly in undisturbed areas. Because of its volatility, releases to the environment usually reach the atmosphere. Here it reacts with hydroxyl or other radicals (estimated half-life for reaction with hydroxyl radicals is less than a week) and is not therefore expected to diffuse to the stratosphere to any significant extent. There is some evidence for both aerobic and anaerobic biodegradation of trichloroethylene.

#### *(xiv) Sick building syndrome*

When working in certain buildings some workers suffer temporarily from a group of symptoms including:

- lethargy/tiredness;
- irritability;
- lack of concentration/mental fatigue;
- headaches;
- nausea/dizziness;
- sore throats;
- dry eyes and skin;
- skin rash;
- asthma;
- blocked/runny nose.

The condition is usually non-specific and seldom traced to a single cause. This has been termed sick building syndrome. Despite much research, little has been proven but the building features associated with the condition are:

- hermetically sealed, airtight shell;
- mechanical heating, ventilation and air-conditioning;
- use of materials and equipment that emit a variety of irritating and sensitizing toxic fumes and/or dust;
- fluorescent lights;
- application of energy conservation measures;
- lack of individual control over environmental conditions;
- landscape plants;
- VDUs;
- draughts.

Whilst the causative agent(s) have not been established it is thought to be multifunctional and possibilities include physical factors (humidity, temperature, lighting), static electricity, electromagnetic radiation, air ion concentrations, fungi, noise, psychological stress, and chemicals. Chemicals which are not those involved in the normal work processes can become trapped within the building, albeit at concentrations below those known to cause ill-health effects, if:

liberated from materials of construction or furnishings; or  
they could enter from outside.

Examples of common pollutants are given in Table 5.53.

**Table 5.53 Common pollutants that may be found in buildings**

| <i>Chemical</i> | <i>Source</i>                                                                                                                                                                                                           |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ammonia         | Cleaning solutions<br>Printers                                                                                                                                                                                          |
| Asbestos        | Cigarette smoke<br>Pipe lagging<br>Air duct linings<br>Ceiling and roof tiles<br>Asbestos cement sheeting                                                                                                               |
| Benzene         | Synthetic fibres<br>Plastics<br>Cleaning solutions<br>Tobacco smoke                                                                                                                                                     |
| Biocides        | Air-conditioning systems<br>Water treatment<br>Humidifiers<br>Disinfectants                                                                                                                                             |
| Carbon dioxide  | Exhaled breath<br>Vehicle exhausts<br>Smoking chimneys<br>Portable heaters                                                                                                                                              |
| Carbon monoxide | Tobacco smoke<br>Gas cookers<br>Gas and oil heaters<br>Vehicle exhausts from loading bays or diesel trucks                                                                                                              |
| Detergent dust  | Carpet cleaners                                                                                                                                                                                                         |
| Ethyl alcohol   | Duplicating fluids                                                                                                                                                                                                      |
| Fibre glass     | Insulation                                                                                                                                                                                                              |
| Formaldehyde    | Insulation material<br>Ceiling tiles<br>Particle board<br>Plywood<br>Office furniture<br>Carpet glues<br>Various plastics<br>Synthetic fibres and rugs<br>Upholstery and other textiles<br>Pesticides<br>Paint<br>Paper |
| Hydrocarbons    | Tobacco smoke<br>Paints, adhesives<br>Solvents<br>Synthetic materials                                                                                                                                                   |

**Table 5.53 Cont'd**

| <i>Chemical</i>    | <i>Source</i>                                                                                              |
|--------------------|------------------------------------------------------------------------------------------------------------|
|                    | Floor and furniture polishes                                                                               |
|                    | Vehicle exhausts                                                                                           |
| Hydrochloric acid  | Electric stencil cutting machines                                                                          |
| Methyl alcohol     | Spirit duplicating machines                                                                                |
| Micro-organisms    | Duct work                                                                                                  |
|                    | Humidifiers                                                                                                |
| Oxides of nitrogen | Vehicle exhausts                                                                                           |
|                    | Tobacco smoke                                                                                              |
|                    | Gas heaters                                                                                                |
| Ozone              | Electrical discharges from equipment such as photocopiers, electrostatic precipitators, fluorescent lights |
| Paint fumes        | Paint                                                                                                      |
| PCBs               | Transformers                                                                                               |
|                    | Ageing VDUs                                                                                                |
|                    | Fluorescent lights                                                                                         |
| Pesticides         | Plant, timber and fabric treatments                                                                        |
|                    | Air conditioning/ventilation units                                                                         |
| Photochemical smog | Reaction between chemicals and ozone                                                                       |
| Radon              | Soil                                                                                                       |
|                    | Concrete                                                                                                   |
|                    | Stone                                                                                                      |
|                    | Water supply                                                                                               |
| Solvents           | Typist correction fluids                                                                                   |
|                    | Adhesives, glues                                                                                           |
|                    | Cleaning fluids                                                                                            |
|                    | Paint                                                                                                      |
|                    | Felt-tip pens                                                                                              |
|                    | Stencil machines                                                                                           |
|                    | Inks                                                                                                       |
| Sterilant gases    | Humidifiers                                                                                                |
|                    | Air-conditioning units                                                                                     |
| Sulphur dioxide    | Coal fires                                                                                                 |
|                    | Power stations                                                                                             |
|                    | Chimneys                                                                                                   |
|                    | Vehicle exhausts                                                                                           |
| Vinyl chloride     | Plastic PVC pipes                                                                                          |
|                    | Light fittings                                                                                             |
|                    | Upholstery                                                                                                 |
|                    | Carpets                                                                                                    |

Because the cause is unknown precautions are difficult to specify but general guidance includes that in Table 5.54.

Temporary problems of building pollution may occur during construction and engineering activities, refurbishment, painting and decorating, and cleaning in internal, or sometimes external, areas. The sources are, generally, more easily traced.

#### *(xv) Synthetic resins*

Synthetic resins are extensively used, e.g., in surface finishes, in the fabrication and repair of boat and motor vehicle bodies, in the manufacture of laminated boards, for electrical components, in pattern making and in paints and varnishes. Non-rubber adhesives made from fish glues and from cotton derivatives (e.g. cellulose acetate) tend not to be sensitizing but, depending upon composition and the manner of use, many other types may pose significant dermatitic and fume hazards.

**Table 5.54 Precautions to avoid 'sick buildings'**


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|                                                                                                            |
|------------------------------------------------------------------------------------------------------------|
| Avoid nuisance noise                                                                                       |
| Provide adequate ventilation                                                                               |
| Avoid high uniform temperatures                                                                            |
| Avoid lack of air movement                                                                                 |
| Provide adequate humidity                                                                                  |
| Avoid uniform dull lighting and décor                                                                      |
| Provide natural lighting: avoid tinted glass                                                               |
| Ensure staff are motivated                                                                                 |
| Consider possible cause at building design, construction and commissioning stages                          |
| 'Bake out' buildings to drive out pollutants                                                               |
| Investigate complaints, especially if there are pockets of complaints, or epidemics with related symptoms. |

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The monomers, catalysts or hardeners, or plasticizers can include chemicals with the potential to irritate the skin, mucous membranes or respiratory tract. Some can promote skin or respiratory sensitization. The range of chemicals in use is extremely wide, so that reference should be made to the Materials Safety Data Sheet for each specific formulation or variation of it identifiable by reference to the supplier's proprietary name and code number. Some common resin types are summarized in Table 5.55.

**Table 5.55 Synthetic resin types**


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| <i>Type</i>  | <i>Examples</i>                                                                                                                                                                                                    |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acrylic      | Polymethyl methacrylate                                                                                                                                                                                            |
| Amino        | Melamine formaldehyde, urea formaldehyde, furfuryl alcohol – urea formaldehyde                                                                                                                                     |
| Epoxy        | Epichlorohydrin with bisphenol A. The curing agents may pose significant health hazards, e.g. amines (triethylamine, <i>p</i> -phenylenediamine, diethylenetriamine) or acid anhydrides (pyromellitic dianhydride) |
| Phenolic     | Phenol formaldehyde. Formaldehyde is a respiratory irritant but is not classified as asthmagen.                                                                                                                    |
| Polyester    | Powder coatings containing triglycidyl isocyanurate are possible asthmagens (unclassified)                                                                                                                         |
| Polyurethane | An organic isocyanate (MDI or a pre-polymer) with a hydroxy compound. The isocyanates are potent respiratory sensitizers, the risk increasing with volatility                                                      |
| Vinyl        | Polyvinyl chloride, polyvinyl acetate.                                                                                                                                                                             |

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With the exception of epoxy resins, when a resin is fully polymerized it loses any irritant properties. However, associated materials, e.g. glass fibre used as a filler, or the dust from plywood or veneers, may promote irritation. Partially-cured resins will retain some irritant properties. Traces of cutaneous or respiratory sensitizers liberated, e.g. by heating or machinery, may be problematic.

Epoxy resins are often mixtures of the epoxy resin, a curing agent (hardener), solvents, reactive diluents, antioxidants and filler. Examples are given in Table 5.56. Curing agents usually comprise peroxides, amines or anhydrides. These may cure at room temperature or require elevated temperatures. They may be irritant or damage skin, eyes or lungs; certain amines and peroxides are sensitizers. The solvents such as acetone, methyl ethyl ketone, toluene, xylene, glycol ethers, and alcohols pose both health and fire hazards. Glycidyl ethers are used as reactive diluents while

**Table 5.56 Typical exposure effects associated with epoxy resin systems**

| <i>Resin type</i>                                | <i>Examples</i>                                                                 | <i>Skin contact</i>                                                                      | <i>Inhalation</i>                                                                                                            | <i>Ingestion</i>                        |
|--------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|
| Liquid epoxy resin                               | based on the reaction product of epichlorohydrin and bisphenol A or bisphenol F | mild to moderate irritants<br>mild to moderate sensitizers                               | low volatility, exposure unlikely unless heated, sprayed, or spread over large unventilated surface                          | low toxicity                            |
| Solid epoxy resins                               | based on the reaction product of epichlorohydrin and bisphenol A or bisphenol F | mild to moderate irritants and mild sensitizers<br>not readily absorbed through skin     | low volatility, exposure unlikely unless crushed or ground                                                                   | low toxicity                            |
| Modified liquid epoxy resins                     | liquid epoxy resins with added reactive diluents or solvents                    | mild to moderate irritants<br>moderate to strong sensitizers                             | low volatility, exposure unlikely unless heated, sprayed, or spread over large unventilated surfaces                         | low toxicity                            |
| Aliphatic and cycloaliphatic amine curing agents | –                                                                               | irritants, sensitizers, corrosive, absorbed through skin                                 | respiratory irritants                                                                                                        | high toxicity                           |
| Aromatic amine curing agents                     | –                                                                               | sensitizers, long-term health effects, absorbed through skin                             | respiratory irritants<br>sensitizers                                                                                         | moderate to high toxicity               |
| Anhydride curing agents                          | –                                                                               | corrosive, severe sensitizers                                                            | dusts may be sensitizers                                                                                                     | high toxicity                           |
| Reactive diluents                                | glycidyl ethers                                                                 | moderate to strong sensitizers                                                           | moderate volatility, exposure possible                                                                                       | low toxicity                            |
| Solvents                                         | acetone, methyl ethyl ketone (MEK), toluene, xylene, glycol, ethers, alcohol    | defats and dries skin<br>some may be absorbed<br>may carry other components through skin | high volatility, exposure possible<br>irritation<br>central nervous system depression (e.g. dizziness, loss of coordination) | low to high toxicity, long-term effects |
| Fillers                                          | fibreglass, silicas, calcium carbonate, powdered metal pigments                 | some may be absorbed<br>potential primary irritant                                       | dust inhalation                                                                                                              | low toxicity                            |

phenols, phosphites, amines and thiobisphenols are employed as antioxidants in, e.g., polypropene, polyethylene and polystyrene resins. Typical precautions are summarized in Table 5.57.

Numerous alternatives to low-solid, solvent-based coatings traditionally used by, e.g., the wood furniture industry are shown in Table 5.58 with the estimated reduction in volatile organic compound emissions.



**Table 5.57 General precautions with synthetic resins**


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|                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Substitution using non-irritant resins and constituents, or less hazardous or less volatile constituents.                                                                                                                            |
| Limitation of skin contact, e.g. by covering benches, pre-mixing of resins, good housekeeping, mechanization.                                                                                                                        |
| Prevent or limit dust and vapour production.                                                                                                                                                                                         |
| Partial enclosure with local exhaust ventilation, or local exhaust ventilation, of working position: separate hazardous processes from other work, e.g. spray-painting with epoxy-containing sensitizing and carcinogenic compounds, |
| Enclose curing and mixing rooms.                                                                                                                                                                                                     |
| Consider in advance procedures to be used for cleaning tools used in the process.                                                                                                                                                    |
| Provision and use of protective clothing, e.g. gloves, gauntlets, armlets, long-sleeved overalls; storage apart from ordinary clothing.                                                                                              |
| Provision and use of appropriate barrier cream.                                                                                                                                                                                      |
| Health surveillance on a regular basis covering skin inspections, enquiries/tests relating to respiratory function: consider the need to screen out staff with medical histories of allergic reactions.                              |
| Provision of first-aid treatment even for trivial injuries to the skin.                                                                                                                                                              |
| Provision of adequate washing facilities including resin-removal cream; enforce high standards of personal hygiene.                                                                                                                  |
| Limitation of the use of respiratory protection to those situations where control of exposure by inhalation cannot be controlled by other means.                                                                                     |
| Provision of a good standard of general ventilation.                                                                                                                                                                                 |
| Prohibition of eating, drinking, smoking or application of cosmetics in the workplace.                                                                                                                                               |
| Plan and organize collection and disposal of waste.                                                                                                                                                                                  |
| Limit stocks, some ingredients such as MbOCA and MEK have potential for major accidents.                                                                                                                                             |

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**Table 5.58 Alternative wood glues**


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| Coating type                      | VOC reduction (%) |
|-----------------------------------|-------------------|
| Aqueous base                      | 90–95             |
| High solids (e.g. nitrocellulose) | 17–40             |
| UV cured                          | 80–100            |
| Polyester                         | 80–100            |
| Polyurethane                      | 80–100            |

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*(xvi) Welding fume*

Almost all welding, brazing, gas cutting, burning and similar processes produce polluting fume and gases which can be harmful. The composition of the fume varies and the quantity generated depends upon the type of process. A summary of the possible emissions is given in Figure 5.4. Generally the fume will comprise very fine particles of metals and their oxides. Gases such as carbon monoxide and nitrogen oxides may be generated and mix with any inert shielding gases used. The hazard may be increased if the metal is painted (e.g. if lead-based paint is present the fume will contain lead oxide) or coated (e.g. plastic coatings will emit thermal degradation products). (Examples are given in Table 5.48.) Metal coatings will also emit thermal degradation products, e.g. zinc oxide fumes from galvanized steel, lead oxide from steel painted with red lead for corrosion protection.

Measures to control welding fume include process modifications, engineering controls, system of work and administrative action as summarized in Figure 5.5.

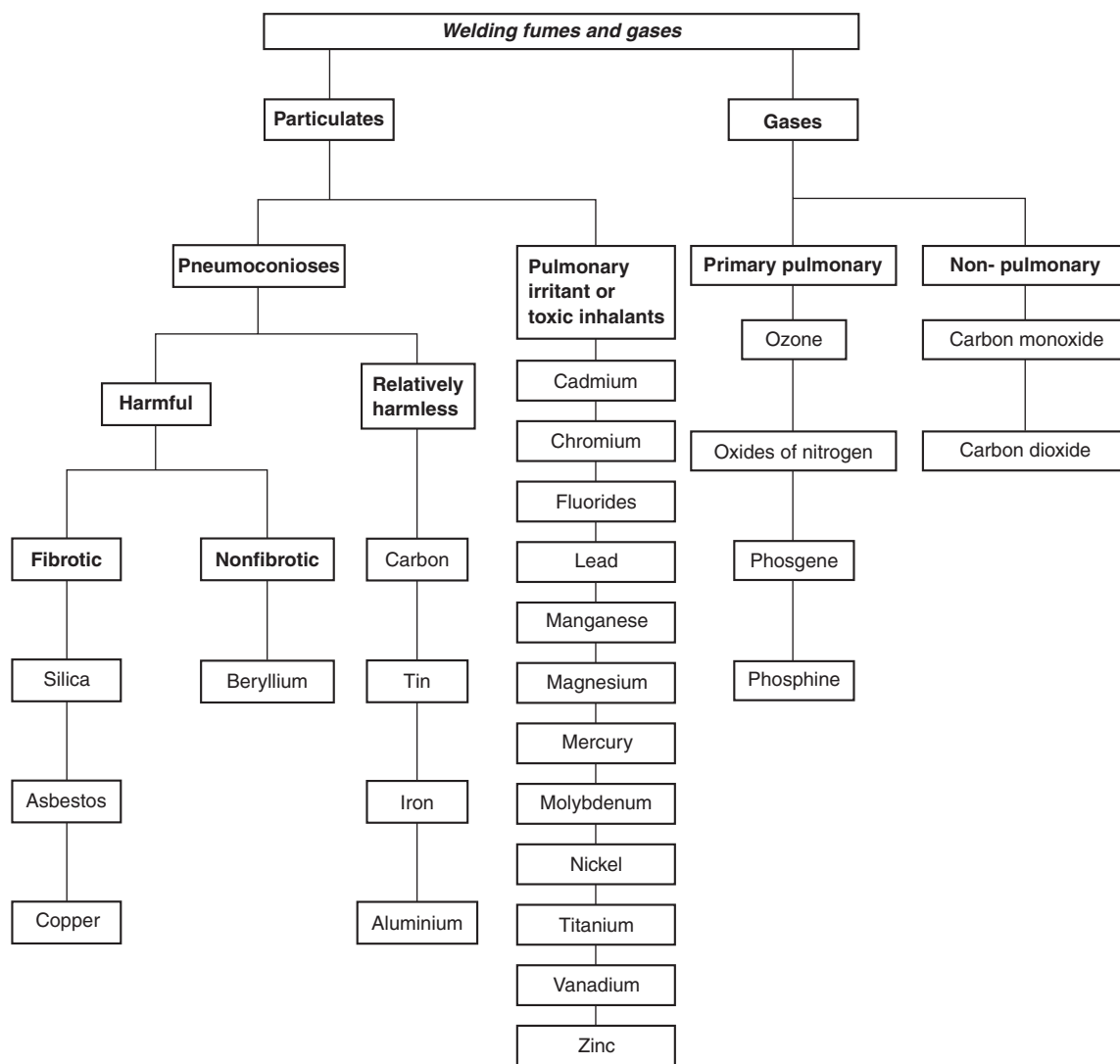


Figure 5.4 Possible constituents in welding fumes and their effects

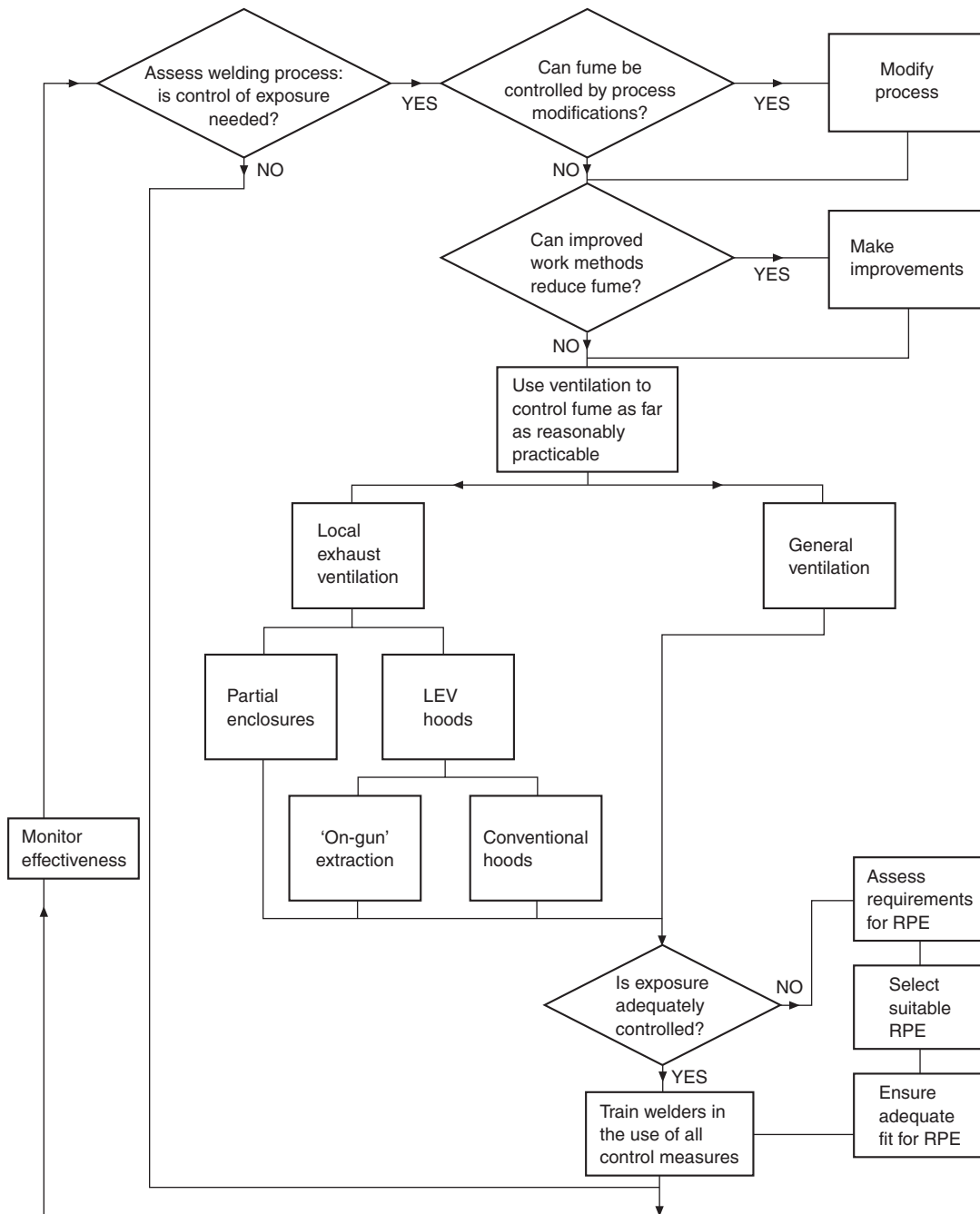


Figure 5.5 Measures to control welding fume

**Table 5.12 Hygiene standards (see key and notes on pages 108–110)**

| Substance                                      | Threshold limit values (USA) |                                     |                              |                                     | Occupational exposure limits (UK) |                      |                              |                      | Air odour threshold (ppm; v/v) |
|------------------------------------------------|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----------------------------------|----------------------|------------------------------|----------------------|--------------------------------|
|                                                | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                |
| Acetaldehyde                                   | –                            | –                                   | C25                          | –                                   | 20                                | 37                   | 50                           | 92                   | 2000                           |
| Acetic acid                                    | 10                           | 25                                  | 15                           | 37                                  | 10                                | 25                   | 15                           | 37                   | 21                             |
| Acetic anhydride                               | 5C                           | –                                   | –                            | –                                   | 0.5                               | 0.1                  | 2                            | 0.4                  | 39                             |
| Acetone                                        | 500                          | –                                   | 750                          | –                                   | 750                               | 1810                 | 1500                         | 3620                 | 57                             |
| Acetone cyanohydrin                            | –                            | –                                   | SKC4.7                       | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Acetonitrile                                   | 40                           | 67                                  | 60                           | 101                                 | 40                                | 68                   | 60                           | 102                  | 0.23                           |
| Acetophenone                                   | 10                           | –                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Acetylene                                      | –                            | (d)                                 | –                            | –                                   | –                                 | (d)                  | –                            | –                    | 230                            |
| Acetylene dichloride, see 1,2-Dichloroethylene |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Acetylene tetrabromide                         | 1                            | 14                                  | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Acetylsalicylic acid (aspirin)                 | –                            | 5                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    | –                              |
| Acrolein                                       | –                            | –                                   | C0.1                         | –                                   | 0.1                               | 0.25                 | 0.3                          | 0.8                  | 0.61                           |
| Acrylamide                                     | SK                           | 0.03 <sup>(e)</sup>                 | –                            | –                                   | SK                                | 0.3 MEL              | –                            | –                    | –                              |
| Acrylic acid                                   | SK                           | 2                                   | 5.9                          | –                                   | 10                                | 30                   | 20                           | 60                   | 110                            |
| Acrylonitrile                                  | SK                           | 2 <sup>(e)</sup>                    | 4.3 <sup>(e)</sup>           | –                                   | SK                                | 4.4 MEL              | –                            | –                    | 0.12                           |
| Adipic acid                                    | –                            | 5                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Adiponitrile                                   | 2                            | –                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Aldrin                                         | SK                           | 0.25                                | –                            | –                                   | SK                                | 0.25                 | –                            | 0.75                 | –                              |
| Allyl alcohol                                  | SK                           | 0.5                                 | –                            | –                                   | SK                                | 4.8                  | 4                            | 9.7                  | 1.8                            |
| Allyl chloride                                 | 1                            | 3                                   | 2                            | 6                                   | –                                 | –                    | –                            | –                    | 0.84                           |
| Allyl glycidyl ether (AGE)                     | 1                            | –                                   | –                            | –                                   | SK                                | 5                    | 24                           | 10                   | 47                             |
| Allyl propyl disulphide                        | 2                            | 12                                  | 3                            | 18                                  | –                                 | –                    | –                            | –                    | –                              |
| α-Alumina, see Aluminium oxide                 |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Aluminium                                      |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Total inhalable dust                           | –                            | –                                   | –                            | –                                   | –                                 | 10                   | –                            | –                    | –                              |
| Respirable dust                                | –                            | –                                   | –                            | –                                   | –                                 | 4                    | –                            | –                    | –                              |
| Metal dust                                     | –                            | 10                                  | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Pyro powders, as Al                            | –                            | 5                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Welding fumes, as Al                           | –                            | 5                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Alkyls (NOC-d), as Al                          | –                            | 2                                   | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Aluminium oxides                               |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Total inhalable dust                           | –                            | 10                                  | –                            | –                                   | –                                 | 10                   | –                            | –                    | –                              |
| Respirable dust                                | –                            | –                                   | –                            | –                                   | –                                 | 4                    | –                            | –                    | –                              |
| Aluminium salts (soluble)                      | –                            | 2                                   | –                            | –                                   | –                                 | 2                    | –                            | –                    | –                              |
| 4-Aminodiphenyl                                | SK                           | (g)                                 | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| 2-Aminoethanol, see Ethanolamine               |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| 2-Aminopyridine                                | 0.5                          | 2                                   | –                            | –                                   | 0.5                               | 2                    | 2                            | 8                    | –                              |
| Amitrole                                       | –                            | 0.2                                 | –                            | –                                   | –                                 | –                    | –                            | –                    | –                              |
| Ammonia                                        | 25                           | 17                                  | 35                           | 24                                  | 25                                | 18                   | 35                           | 25                   | 4.8                            |

|                                                |    |                    |                         |      |       |      |        |      |       |       |
|------------------------------------------------|----|--------------------|-------------------------|------|-------|------|--------|------|-------|-------|
| Ammonium chloride fume                         |    | –                  | 10                      | –    | 20    | –    | 10     | –    | 20    |       |
| Ammonium perfluorooctanoate                    | SK | –                  | 0.01                    | –    | –     | –    | –      | –    | –     |       |
| Ammonium sulphamate                            |    | –                  | 10                      | –    | –     | –    | 10     | –    | 20    |       |
| Amosite, see Asbestos                          |    |                    |                         |      |       |      |        |      |       |       |
| <i>n</i> -Amyl acetate                         |    | 50                 | –                       | 100  | –     | 50   | 270    | 100  | 541   | 1800  |
| sec-Amyl acetate                               |    | 50                 | –                       | 100  | –     | 50   | 270    | 100  | 541   | 61000 |
| Aniline and homologues                         | SK | 2                  | 7.6                     | –    | –     | SK   | 1      | 4    | –     | 1.9   |
| Anisidine (o-, p-isomers)                      | SK | 0.1                | 0.5                     | –    | –     | SK   | 0.1    | 0.5  | –     |       |
| Antimony and antimony compounds                |    |                    |                         |      |       |      |        |      |       |       |
| except stibine (as Sb)                         |    | –                  | 0.5                     | –    | –     | –    | 0.5    | –    | –     |       |
| Antimony hydride (Stibine)                     |    | 0.1                | –                       | –    | –     | 0.1  | 0.52   | 0.3  | 1.6   |       |
| Antimony trioxide production                   |    | (g)                | –                       | –    | –     | –    | –      | –    | –     |       |
| <i>p</i> -Aramid respirable fibres (1)         |    |                    |                         |      |       | –    | –      | –    | –     |       |
| ANTU                                           |    | –                  | 0.3                     | –    | –     | –    | –      | –    | –     |       |
| Argon                                          |    | –                  | (d)                     | –    | –     | –    | (d)    | –    | –     |       |
| Arsenic elemental and inorganic compounds As   |    | –                  | 0.01 <sup>(g)</sup>     | –    | –     | –    | –      | –    | –     |       |
| Arsenic trioxide production                    |    | –                  | (e)                     | –    | –     | –    | –      | –    | –     |       |
| Arsine                                         |    | 0.05               | 0.16                    | –    | –     | 0.05 | 0.16   | –    | –     | 0.10  |
| Asbestos, all forms <sup>(g)</sup>             |    |                    | 0.1                     | –    | –     | (j)  |        |      |       |       |
|                                                |    |                    | Fibre/cc <sup>(h)</sup> |      |       |      |        |      |       |       |
| Asphalt (petroleum) fumes                      |    | –                  | 0.5                     | –    | –     | –    | 5      | –    | 10    |       |
| Atrazine                                       |    | –                  | 5                       | –    | –     | –    | 10     | –    | –     |       |
| Azinphos-methyl                                | SK | –                  | 0.2                     | –    | –     | SK   | –      | 0.2  | –     | 0.6   |
| Azodicarbonamide                               |    | –                  | –                       | –    | –SEN  | –    | 1.0    | –    | 3 MEL |       |
| Barium, soluble compounds, as Ba               |    | –                  | 0.5                     | –    | –     | –    | 0.5    | –    | –     |       |
| Barium sulphate                                |    |                    |                         |      |       |      |        |      |       |       |
| Respirable dust                                |    | –                  | –                       | –    | –     | –    | 4      | –    | –     |       |
| Total inhalable dust                           |    | –                  | 10                      | –    | –     | –    | 10     | –    | –     |       |
| Benomyl                                        |    | –                  | 10                      | –    | –     | –    | 10     | –    | 15    |       |
| Benzene                                        |    | 0.5 <sup>(g)</sup> | –                       | 2.5  | –     | 5    | 15 MEL | –    | –     | 0.85  |
| Benz(a)anthrene                                |    | (e)                |                         |      |       |      |        |      |       |       |
| Benzenethiol                                   |    | –                  | –                       | –    | –     | 0.5  | 2.3    | –    | –     |       |
| Benzene-1,2,4-tricarboxylic acid 1,2-anhydride |    | –                  | –                       | –    | C0.04 | SEN  | –      | 0.04 | –     | 0.12  |
| Benzidine                                      | SK | –                  | (g)                     | –    | –     | –    | –      | –    | –     |       |
| <i>p</i> -Benzoquinone, see Quinone            |    |                    |                         |      |       |      |        |      |       |       |
| Benzo(b)fluoranthene                           |    | (e)                |                         |      |       |      |        |      |       |       |
| Benzoyl peroxide                               |    | –                  | 5                       | –    | –     | –    | 5      | –    | –     |       |
| Benzo(a)pyrene                                 |    | –                  | (e)                     | –    | –     | –    | –      | –    | –     |       |
| Benzotrichloride                               | SK | (e)                | –                       | C0.1 | –     | –    | –      | –    | –     |       |
| Benzoyl chloride                               |    | –                  | –                       | C0.5 | –     | –    | –      | –    | –     |       |

(1) *p*-Aramid respirable fibres are subject to an OES of 0.5 fibres/ml, 8 hr TWA

Table 5.12 Cont'd

| Substance                                                          | Threshold limit values (USA) |                                     |                           |                                     | Occupational exposure limits (UK) |                      |                           |                      | Air odour threshold (ppm; v/v) |
|--------------------------------------------------------------------|------------------------------|-------------------------------------|---------------------------|-------------------------------------|-----------------------------------|----------------------|---------------------------|----------------------|--------------------------------|
|                                                                    | TWA (ppm) <sup>(a)</sup>     | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL (ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup> (ppm)          | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup> (ppm) | (mg/m <sup>3</sup> ) |                                |
| Benzyl acetate                                                     | 10                           | —                                   | —                         | —                                   | —                                 | —                    | —                         | —                    |                                |
| Benzyl butyl phthalate                                             | —                            | —                                   | —                         | —                                   | —                                 | 5                    | —                         | —                    |                                |
| Benzyl chloride                                                    | 1                            | 5.2                                 | —                         | —                                   | 0.5                               | 2.6                  | 1.5                       | 7.9                  | 23                             |
| Beryllium and compounds, as Be                                     | —                            | 0.002 <sup>(g)</sup>                | —                         | 0.01                                | —                                 | 0.002                | —                         | —                    |                                |
| Biphenyl                                                           | 0.2                          | 1.3                                 | —                         | —                                   | 0.2                               | 1.3                  | 0.6                       | 3.8                  | 240                            |
| 2,2-Bis(p-chlorophenyl)-1,1,1-trichloroethane see Diglycidyl ether | —                            | —                                   | —                         | —                                   | —                                 | 1                    | —                         | 3                    |                                |
| Bis(2-dimethylamino-ethyl) ether                                   | 0.05                         | —                                   | 0.15                      | —                                   | —                                 | —                    | —                         | —                    |                                |
| Bis(2-ethyl hexyl) phthalate                                       | —                            | —                                   | —                         | —                                   | —                                 | 5                    | —                         | 10                   |                                |
| Bismuth telluride                                                  | —                            | 10                                  | —                         | —                                   | —                                 | 10                   | —                         | 20                   |                                |
| Se-doped                                                           | —                            | 5                                   | —                         | —                                   | —                                 | 5                    | —                         | 10                   |                                |
| Borates, tetra, sodium salts                                       |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| Anhydrous                                                          | —                            | 1                                   | —                         | —                                   | —                                 | 1                    | —                         | —                    |                                |
| Decahydrate                                                        | —                            | 5                                   | —                         | —                                   | —                                 | 5                    | —                         | —                    |                                |
| Pentahydrate                                                       | —                            | 1                                   | —                         | —                                   | —                                 | 1                    | —                         | —                    |                                |
| Bornan-2-one                                                       | 2                            | —                                   | 4                         | —                                   | 2                                 | 13                   | 3                         | 19                   |                                |
| Boron oxide                                                        | —                            | 10                                  | —                         | —                                   | —                                 | 10                   | —                         | 20                   |                                |
| Boron tribromide                                                   | —                            | —                                   | C1                        | —                                   | —                                 | —                    | 1                         | 10                   |                                |
| Boron trifluoride                                                  | —                            | —                                   | C1                        | —                                   | —                                 | —                    | 1                         | 2.8                  |                                |
| Bromacil                                                           | —                            | 10                                  | —                         | —                                   | 1                                 | 11                   | 2                         | 22                   |                                |
| Bromine                                                            | 0.1                          | 0.66                                | 2                         | 1.3                                 | 0.1                               | 0.7                  | 0.3                       | 2                    |                                |
| Bromine pentafluoride                                              | 0.1                          | 0.72                                | —                         | —                                   | 0.1                               | 0.7                  | 0.3                       | 2.2                  | 2.0                            |
| Bromochloromethane, see Chlorobromomethane                         |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| Bromoethane, see Ethyl bromide                                     |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| Bromoform                                                          | SK                           | 0.5                                 | 5.2                       | —                                   | SK                                | 0.5                  | 5                         | —                    | 0.39                           |
| Bromomethane, see Methyl bromide                                   |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| Bromotrifluoromethane                                              | 1000                         | 6190                                | —                         | —                                   | 1000                              | 6190                 | 1200                      | 7430                 |                                |
| 1,3-Butadiene                                                      | 2 <sup>(e)</sup>             | —                                   | —                         | —                                   | 10                                | 22 MEL               | —                         | —                    | 640                            |
| Butane                                                             | 800                          | 1900                                | —                         | —                                   | 600                               | 1450                 | 750                       | 1810                 | 0.29                           |
| Butanethiol, see Butyl mercaptan                                   |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| 2-Butanone, see Methyl ethyl ketone (MEK)                          |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |
| trans-But-2-enal                                                   | —                            | —                                   | —                         | —                                   | 2                                 | 6                    | 6                         | 18                   |                                |
| 2-Butoxyethanol (EGBE)                                             | SK                           | 20                                  | —                         | —                                   | SK                                | 25                   | 123 MEL                   | —                    | 250                            |
| n-Butyl acetate                                                    | 150                          | 713                                 | 200                       | 950                                 | 150                               | 724                  | 200                       | 966                  | 390                            |
| sec-Butyl acetate                                                  | 200                          | 950                                 | —                         | —                                   | 200                               | 966                  | 250                       | 1210                 |                                |

|                                          |    |     |                      |     |      |    |     |                                             |     |          |      |
|------------------------------------------|----|-----|----------------------|-----|------|----|-----|---------------------------------------------|-----|----------|------|
| tert-Butyl acetate                       |    | 200 | 950                  | –   | –    |    | 200 | 966                                         | 250 | 1210     |      |
| Butyl acrylate                           |    | 2   | –                    | –   | –    |    | 10  | 53                                          | –   | –        | 290  |
| <i>n</i> -Butyl alcohol                  | SK | –   | –                    | C50 | –    | SK | –   | –                                           | 50  | 154      | 60   |
| sec-Butyl alcohol                        |    | 100 | 303                  | –   | –    |    | 100 | 308                                         | 150 | 462      | 38   |
| tert-Butyl alcohol                       |    | 100 | 303                  | –   | –    |    | 100 | 308                                         | 150 | 462      | 2.1  |
| Butylamine                               | SK | –   | –                    | C5  | –    | SK | –   | –                                           | 5   | 15       | 2.7  |
| <i>n</i> -Butyl chloroformate            |    | –   | –                    | –   | –    |    | 1   | 5.6                                         | –   | –        |      |
| tert-Butyl chromate, as CrO <sub>3</sub> | SK | –   | –                    | –   | C0.1 |    | –   | –                                           | –   | –        |      |
| Butylated hydroxy toluene                |    | –   | 10                   | –   | –    |    | –   | 10                                          | –   | –        |      |
| <i>n</i> -Butyl glycidyl ether (BGE)     |    | 25  | 133                  | –   | –    |    | 25  | 135                                         | –   | –        |      |
| <i>n</i> -Butyl lactate                  |    | 5   | 30                   | –   | –    |    | 5   | 30                                          | –   | –        | 0.71 |
| Butyl mercaptan                          |    | 0.5 | 1.8                  | –   | –    |    | –   | –                                           | –   | –        | 510  |
| <i>o</i> -sec-Butylphenol                | SK | 5   | 31                   | –   | –    | SK | 5   | 30                                          | –   | –        |      |
| <i>p</i> -tert-Butyltoluene              |    | 1   | 6                    | 20  | 121  |    | –   | –                                           | –   | –        | 2.0  |
| Cadmium dusts and salts, as Cd           |    |     |                      |     |      |    |     |                                             |     |          |      |
| elemental                                |    | –   | 0.01 <sup>(e)</sup>  | –   | –    |    |     | –                                           |     |          |      |
| compounds, as Cd                         |    | –   | 0.002 <sup>(e)</sup> | –   | –    |    |     | (except<br>cadmium<br>sulphide<br>pigments) |     |          |      |
| Cadmium oxide                            |    |     |                      |     |      |    |     |                                             |     |          |      |
| fume, as Cd                              |    | –   | –                    | –   | –    |    | –   | 0.025 MEL                                   |     | 0.05 MEL |      |
| Cadmium sulphide pigments,               |    | –   | –                    | –   | –    |    | –   | 0.03 MEL                                    | –   | –        |      |
| respirable dust, as Cd                   |    |     |                      |     |      |    |     |                                             |     |          |      |
| Caesium hydroxide                        |    | –   | 2                    | –   | –    |    | –   | 3                                           | –   | –        |      |
| Calcium carbonate                        |    | –   | 10 <sup>(f)</sup>    | –   | –    |    | –   | 10 (total<br>inhalable dust)                | –   | –        |      |
|                                          |    |     |                      |     |      |    |     | 4                                           | –   | –        |      |
|                                          |    |     |                      |     |      |    |     | (respirable dust)                           |     |          |      |
| Calcium chromate                         |    | –   | 0.001 <sup>(e)</sup> | –   | –    | –  | –   | –                                           | –   | –        |      |
| Calcium cyanamide                        |    | –   | 0.5                  | –   | –    | –  | –   | 0.5                                         | –   | 1        |      |
| Calcium hydroxide                        |    | –   | 5                    | –   | –    |    | –   | 5                                           | –   | –        |      |
| Calcium oxide                            |    | –   | 2                    | –   | –    |    | –   | 2                                           |     |          |      |
| Calcium silicate                         |    | –   | 10 <sup>(f)</sup>    | –   | –    |    | –   | 10 (total<br>inhalable dust)                | –   | –        |      |
|                                          |    |     |                      |     |      |    |     | 4                                           |     |          |      |
|                                          |    |     |                      |     |      |    |     | (respirable dust)                           |     |          |      |
| Calcium sulphate                         |    | –   | 10 <sup>(f)</sup>    | –   | –    |    | –   | 10 (total<br>inhalable dust)                | –   | –        |      |
|                                          |    |     |                      |     |      |    |     | 4                                           |     |          |      |
|                                          |    |     |                      |     |      |    |     | (respirable dust)                           |     |          |      |
| Camphor, synthetic, see Bornan-2-one     |    |     |                      |     |      |    |     |                                             |     |          |      |
| Caprolactam                              |    |     |                      |     |      |    |     |                                             |     |          |      |
| Dust                                     |    | –   | 1                    | –   | 3    |    | –   | 1                                           | –   | 3        |      |
| Vapour                                   |    | 5   | 23                   | 10  | 47   |    | 5   | 23                                          | 10  | 47       |      |

Table 5.12 Cont'd

[illegible]



2-Chloroethanol, see Ethylene  
chlorohydrin

Chloroethylene, see Vinyl chloride

|                                                         |                      |                       |    |     |       |                           |     |     |      |
|---------------------------------------------------------|----------------------|-----------------------|----|-----|-------|---------------------------|-----|-----|------|
| Chloroform                                              | 10 <sup>(e)</sup>    | 49 <sup>(e)</sup>     | —  | —   | 2     | 9.9                       | —   | —   | 0.12 |
| bis(Chloromethyl)ether                                  | 0.001 <sup>(g)</sup> | 0.005                 | —  | —   | 0.001 | 0.005                     | —   | —   |      |
| Chloromethyl methyl ether                               | <sup>(e)</sup>       | <sup>(e)</sup>        | —  | —   | —     | —                         | —   | —   |      |
| 1-Chloro-4-nitrobenzene                                 | —                    | —                     | —  | —   | SK    | 1                         | —   | 2   |      |
| 1-Chloro-1-nitropropane                                 | 2                    | 10                    | —  | —   | —     | —                         | —   | —   |      |
| Chloropentafluoroethane                                 | 1000                 | 6420                  | —  | —   | 1000  | 6420                      | —   | —   |      |
| Chloropicrin                                            | 0.1                  | 0.67                  | —  | —   | 0.1   | 0.7                       | 0.3 | 2   | 0.13 |
| β-Chloroprene                                           | SK                   | 36                    | —  | —   | —     | —                         | —   | —   | 0.68 |
| 3-Chloropropene                                         | —                    | —                     | —  | —   | 1     | 3                         | 2   | 6   |      |
| 2-Chloropropionic acid                                  | 0.1                  | —                     | —  | —   | —     | —                         | —   | —   |      |
| o-Chlorostyrene                                         | 50                   | 283                   | 75 | 425 | —     | —                         | —   | —   |      |
| Chlorosulphonic acid                                    | —                    | —                     | —  | —   | —     | 1                         | —   | —   |      |
| o-Chlorotoluene                                         | 50                   | 259                   | —  | —   | 50    | 264                       | —   | —   | 150  |
| 2-Chloro-6-(trichloromethyl)pyridine,<br>see Nitrapyrin |                      |                       |    |     |       |                           |     |     |      |
| Chlorpyrifos                                            | —                    | 0.2                   | —  | —   | SK    | 0.2                       | —   | 0.6 |      |
| Chromite ore processing (Chromate),<br>as Cr            | —                    | 0.05 <sup>(g)</sup>   | —  | —   | —     | —                         | —   | —   |      |
| Chromium metal                                          | —                    | 0.5                   | —  | —   | —     | 0.5                       | —   | —   |      |
| Chromium (III) compounds, as Cr                         | —                    | 0.5                   | —  | —   | —     | 0.5                       | —   | —   |      |
| Chromium (VI) compounds, as Cr                          |                      |                       |    |     |       |                           |     |     |      |
| Water soluble                                           | —                    | 0.05 <sup>(g)</sup>   | —  | —   | }     | 0.05                      | —   | —   |      |
| Water insoluble                                         | —                    | 0.01 <sup>(g)</sup>   | —  | —   |       |                           |     |     |      |
| Chromyl chloride                                        | 0.025                | 0.16                  | —  | —   | —     | —                         | —   | —   |      |
| Chrysene                                                | <sup>(e)</sup>       | <sup>(e)</sup>        | —  | —   | —     | —                         | —   | —   |      |
| Chrysotile, see Asbestos                                |                      |                       |    |     |       |                           |     |     |      |
| Clopidol                                                | —                    | 10                    | —  | —   | —     | —                         | —   | —   |      |
| Coal dust                                               | —                    | 2                     | —  | —   | —     | 2                         | —   | —   |      |
|                                                         |                      | (respirable fraction) |    |     |       | (respirable dust)         |     |     |      |
| Anthracite                                              | —                    | 0.4                   | —  | —   | —     | —                         | —   | —   |      |
| Bitumous                                                | —                    | 0.9                   | —  | —   | —     | —                         | —   | —   |      |
| Coal tar pitch volatiles, as benzene<br>solubles        | —                    | 0.2 <sup>(g)</sup>    | —  | —   | —     | 0.14                      | —   | —   |      |
| Cobalt as Co, elemental and inorganic<br>compounds      | —                    | 0.02                  | —  | —   | —     | 0.1                       | —   | —   |      |
|                                                         |                      |                       |    |     |       | (cobalt and<br>compounds) |     |     |      |
| Cobalt carbonyl as Co                                   | —                    | 0.1                   | —  | —   | —     | —                         | —   | —   |      |
| Cobalt hydrocarbonyl as Co                              | —                    | 0.1                   | —  | —   | —     | —                         | —   | —   |      |
| Copper                                                  |                      |                       |    |     |       |                           |     |     |      |
| Fume                                                    | —                    | 0.2                   | —  | —   | —     | 0.2                       | —   | —   |      |
| Dusts and mists as Cu                                   | —                    | 1                     | —  | —   | —     | 1                         | —   | 2   |      |
| Cotton dust, raw                                        | —                    | 0.2 <sup>(l)</sup>    | —  | —   | —     | 2.5                       | —   | —   |      |

Table 5.12 Cont'd

| Substance                                                       |    | Threshold limit values (USA) |                                     |                              |                                     | Occupational exposure limits (UK) |                      |                              |                      | Air odour<br>threshold<br>(ppm; v/v) |
|-----------------------------------------------------------------|----|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----------------------------------|----------------------|------------------------------|----------------------|--------------------------------------|
|                                                                 |    | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                      |
| Cresol, all isomers                                             | SK | 5                            | 22                                  | –                            | –                                   | SK                                | 5                    | 22                           | –                    | 17 000<br>(m-cresol)                 |
| Cristobalite, see Silica, crystalline                           |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| Crocidolite, see Asbestos                                       |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| Crotonaldehyde                                                  |    | –                            | –                                   | C0.3                         | –                                   | –                                 | –                    | –                            | –                    | 17 (trans)                           |
| Crufomate                                                       |    | –                            | 5                                   | –                            | –                                   | –                                 | –                    | –                            | –                    |                                      |
| Cryofluorane (INN)                                              |    | 1000                         | 7110                                | –                            | –                                   | 1000                              | 7110                 | 1250                         | 8890                 |                                      |
| Cumene                                                          | SK | 50                           | 246                                 | –                            | –                                   | SK                                | 25                   | 125                          | 75                   | 570                                  |
| Cyanamide                                                       |    | –                            | 2                                   | –                            | –                                   | –                                 | 2                    | –                            | –                    |                                      |
| Cyanides as CN, see Hydrogen cyanide                            |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| Cyanogen                                                        |    | 10                           | 22                                  | –                            | –                                   | 10                                | 22                   | –                            | –                    |                                      |
| Cyanogen chloride                                               |    | –                            | –                                   | C0.3                         | C0.75                               | –                                 | –                    | 0.3                          | 0.77                 |                                      |
| Cyclohexane                                                     |    | 300                          | 1030                                | –                            | –                                   | 100                               | 350                  | 300                          | 1050                 | 25                                   |
| Cyclohexanol                                                    | SK | 50                           | 206                                 | –                            | –                                   | 50                                | 208                  | –                            | –                    | 0.15                                 |
| Cyclohexanone                                                   | SK | 25                           | 100                                 | –                            | –                                   | 25                                | 102                  | 100                          | 408                  | 0.88                                 |
| Cyclohexene                                                     |    | 300                          | 1010                                | –                            | –                                   | 300                               | 1020                 | –                            | –                    | 0.18                                 |
| Cyclohexylamine                                                 |    | 10                           | 41                                  | –                            | –                                   | SK                                | 10                   | 41                           | –                    | 2.6                                  |
| Cyclonite                                                       | SK | –                            | 0.5                                 | –                            | –                                   | SK                                | –                    | 1.5                          | –                    | 3                                    |
| Cyclopentadiene                                                 |    | 75                           | 203                                 | –                            | –                                   | –                                 | –                    | –                            | –                    | 1.9                                  |
| Cyclopentane                                                    |    | 600                          | 1720                                | –                            | –                                   | –                                 | –                    | –                            | –                    |                                      |
| Cyhexatin                                                       |    | –                            | 5                                   | –                            | –                                   | –                                 | 5                    | –                            | 10                   |                                      |
| 2,4-D                                                           |    | –                            | 10                                  | –                            | –                                   | –                                 | 10                   | –                            | 20                   |                                      |
| DDT (Dichloro-<br>diphenyltrichloroethane)                      |    | –                            | 1                                   | –                            | –                                   | –                                 | 1                    | –                            | 3                    |                                      |
| Decaborane                                                      | SK | 0.05                         | 0.25                                | 0.15                         | 0.75                                | –                                 | –                    | –                            | –                    |                                      |
| Demeton                                                         | SK | 0.01                         | 0.11                                | –                            | –                                   | –                                 | –                    | –                            | –                    | 0.060                                |
| Diacetone alcohol                                               |    | 50                           | 238                                 | –                            | –                                   | 50                                | 240                  | 75                           | 362                  | 0.28                                 |
| Dialkyl 79 phthalate                                            |    | –                            | –                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    |                                      |
| Diallyl phthalate                                               |    | –                            | –                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    |                                      |
| 2,2'-Diaminodiethylamine                                        |    | –                            | –                                   | –                            | –                                   | SK                                | 1                    | 4                            | –                    |                                      |
| 1,2-Diaminoethane, see Ethylenediamine                          |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| Diammonium peroxydisulphate<br>as S <sub>2</sub> O <sub>8</sub> |    | –                            | –                                   | –                            | –                                   | –                                 | 1                    | –                            | –                    |                                      |
| Diatomaceous earth, see Silica,<br>amorphous                    |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| Diazinon                                                        | SK | –                            | 0.1                                 | –                            | –                                   | SK                                | –                    | 0.1                          | –                    | 0.3                                  |
| Diazomethane                                                    |    | 0.2 <sup>(e)</sup>           | 0.34                                | –                            | –                                   | carcinogen                        | –                    | –                            | –                    |                                      |
| Diborane                                                        |    | 0.1                          | 0.11                                | –                            | –                                   | 0.1                               | 0.1                  | –                            | –                    | 2.5                                  |
| Dibromodifluoromethane                                          |    | –                            | –                                   | –                            | –                                   | 100                               | 872                  | 150                          | 1310                 |                                      |

|                                                           |    |                      |                   |      |       |      |         |           |      |                        |
|-----------------------------------------------------------|----|----------------------|-------------------|------|-------|------|---------|-----------|------|------------------------|
| 1,2-Dibromoethane, <i>see</i> Ethylene dibromide          |    |                      |                   |      |       |      |         |           |      |                        |
| 2- <i>N</i> -Dibutylamino-ethanol                         | SK | 0.5                  | 3.5               | —    | —     | —    | —       | —         | —    | —                      |
| Dibutyl phenyl phosphate                                  | SK | 0.3                  | 3.5               | —    | —     | —    | —       | —         | —    | —                      |
| Dibutyl phosphate                                         |    | 1                    | 8.6               | 2    | 17    | 1    | 8.7     | 2         | 17   |                        |
| Dibutyl phthalate                                         |    | —                    | 5                 | —    | —     | —    | 5       | —         | 10   |                        |
| 6,6'-Di- <i>tert</i> -butyl-4-4'-thiodi- <i>m</i> -cresol |    | —                    | —                 | —    | —     | —    | 10      | —         | 20   |                        |
| Dichloroacetylene                                         |    | —                    | —                 | C0.1 | C0.39 | —    | —       | 0.1       | 0.4  |                        |
| <i>o</i> -Dichlorobenzene                                 | SK | 25                   | 152               | 50   | 153   | —    | —       | 50        | 306  | 0.30                   |
| <i>p</i> -Dichlorobenzene                                 |    | 10                   | 31 <sup>(e)</sup> | —    | —     | 25   | 153     | 50        | 306  | 0.18                   |
| 3-3'-Dichlorobenzidine                                    |    | —                    | —                 | —    | —     | —    | —       | —         | —    |                        |
| 1,4-Dichloro-2-butene                                     |    | 0.005 <sup>(e)</sup> | —                 | —    | —     | —    | —       | —         | —    |                        |
| Dichlorodifluoromethane                                   | SK | 1000                 | 4950              | —    | —     | 1000 | 5030    | 1250      | 6280 |                        |
| 1,3-Dichloro-5,5-dimethyl hydanton                        |    | —                    | 0.2               | —    | 0.4   | —    | 0.2     | —         | —    | 0.4                    |
| 1,1-Dichloroethane                                        |    | —                    | —                 | —    | —     | 200  | 823     | 400       | 1650 |                        |
| 1,2-Dichloroethane, <i>see</i> Ethylene dichloride        |    |                      |                   |      |       |      |         |           |      |                        |
| 1,1-Dichloroethylene <i>see</i> Vinylidene chloride       |    |                      |                   |      |       |      |         |           |      |                        |
| 1,2-dichloroethylene                                      |    | 200                  | 793               | —    | —     | 200  | 806     | 250       | 1010 | 17<br>(trans)<br>0.049 |
| Dichloroethyl ether                                       | SK | 5                    | 29                | 10   | 58    | —    | —       | —         | —    |                        |
| Dichlorofluoromethane                                     |    | 10                   | 42                | —    | —     | 10   | 43      | —         | —    |                        |
| Dichloromethane                                           |    | 50                   | 175               | —    | —     | 100  | 350 MEL | 300       | 1060 |                        |
| 1,1-Dichloro-1-nitroethane                                |    | 2                    | 12                | —    | —     | —    | —       | —         | —    |                        |
| 2,2'-Dichloro-4-4'-methylene dianiline (Mb OCA)           |    | —                    | —                 | —    | —     | SK   | —       | 0.005 MEL | —    |                        |
| Dichlorophenoxyacetic acid, <i>see</i> 2,4-D              |    |                      |                   |      |       |      |         |           |      |                        |
| 1,2-Dichloropropane, <i>see</i> Propylene dichloride      |    |                      |                   |      |       |      |         |           |      |                        |
| Dichloropropene                                           | SK | 1                    | 4.5               | —    | —     | SK   | 1       | 5         | 10   | 50                     |
| 2,2-Dichloropropionic acid                                |    | —                    | 5                 | —    | —     | —    | —       | —         | —    |                        |
| Dichlorotetrafluoro-ethane, <i>see</i> Cryofluorane       |    |                      |                   |      |       |      |         |           |      |                        |
| Dichlorvos                                                | SK | —                    | 0.90              | —    | —     | SK   | 0.1     | 0.92      | 0.3  | 2.8                    |
| Dicrotophos                                               | SK | —                    | 0.25              | —    | —     | —    | —       | —         | —    |                        |
| Dicyclohexyl phthalate                                    |    | —                    | —                 | —    | —     | —    | 5       | —         | —    |                        |
| Dicyclopentadiene                                         |    | 5                    | 27                | —    | —     | 5    | 27      | —         | —    | 0.0057                 |
| Dicyclopentadienyl iron, <i>see</i> Ferrocene             |    |                      |                   |      |       |      |         |           |      |                        |
| Dieldrin                                                  | SK | —                    | 0.25              | —    | —     | SK   | —       | 0.25      | —    | 0.75                   |
| Diethanolamine                                            |    | —                    | 2                 | —    | —     | 3    | 13      | —         | —    | 0.27                   |
| Diethylamine                                              |    | 5                    | —                 | 25   | 75    | 10   | 30      | 25        | 75   | 0.13                   |
| 2-Diethylamino-ethanol                                    | SK | 2                    | —                 | —    | —     | SK   | 10      | 49        | —    | 0.011                  |
| Diethylene glycol                                         |    | —                    | —                 | —    | —     | 23   | 100     | —         | —    |                        |

Table 5.12 Cont'd

| Substance                                                   |    | Threshold limit values (USA) |                                     |                              |                                     | Occupational exposure limits (UK) |                      |                              |                      | Air odour threshold (ppm; v/v) |
|-------------------------------------------------------------|----|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----------------------------------|----------------------|------------------------------|----------------------|--------------------------------|
|                                                             |    | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                |
| Diethylene triamine                                         | SK | 1                            | 4.2                                 | –                            | –                                   | SK                                | 1                    | 4.3                          | –                    | –                              |
| Diethyl ether, see Ethyl ether                              |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Di(2-ethylhexyl)phthalate, see Di-sec-octyl phthalate       |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Diethyl ketone                                              |    | 200                          | 716                                 | 300                          | 1024                                | 200                               | 716                  | 250                          | 895                  | 2.0                            |
| Diethyl phthalate                                           |    | –                            | 5                                   | –                            | –                                   | –                                 | 5                    | –                            | 10                   |                                |
| Diethyl sulphate                                            |    | –                            | –                                   | –                            | –                                   | 0.05                              | 0.32                 | –                            | –                    |                                |
| Difluorodibromomethane                                      |    | 100                          | 858                                 | –                            | –                                   | 100                               | 860                  | 150                          | 1290                 |                                |
| Diglycidyl ether (DGE)                                      |    | 0.1                          | 0.53                                | –                            | –                                   | 0.1                               | 0.5                  | –                            | –                    |                                |
| Dihydroxybenzene, see Hydroquinone                          |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Diisobutyl ketone                                           |    | 25                           | 145                                 | –                            | –                                   | 25                                | 148                  | –                            | –                    | 0.11                           |
| Diisooctyl phthalate                                        |    | –                            | –                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    |                                |
| Diisodecyl phthalate                                        |    | –                            | –                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    |                                |
| Diisononyl phthalate                                        |    | –                            | –                                   | –                            | –                                   | –                                 | 5                    | –                            | –                    |                                |
| Diisopropylamine                                            | SK | 5                            | 21                                  | –                            | –                                   | 5                                 | 21                   | –                            | –                    | 1.8                            |
| Diisopropyl ether, see Isopropyl ether                      |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethoxymethane, see Methylal                              |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethyl acetamide                                          | SK | 10                           | 36                                  | –                            | –                                   | SK                                | 10                   | 36                           | 20                   | 47                             |
| Dimethylamine                                               |    | 5                            | 9                                   | 15                           | 27                                  |                                   | 2                    | 3.8                          | 6                    | 0.34                           |
| Dimethylaminobenzene, see Xylidene                          |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethylamino ethanol                                       |    | –                            | –                                   | –                            | –                                   | 2                                 | 7.4                  | 6                            | 22                   |                                |
| Dimethylaniline                                             | SK | 5                            | 25                                  | 10                           | 50                                  | SK                                | 5                    | 25                           | 10                   | 0.013                          |
| (N,N-Dimethylaniline)                                       |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethylbenzene, see Xylene                                 |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| 1,3-Dimethylbutyl acetate                                   |    | –                            | –                                   | –                            | –                                   | 50                                | 300                  | 100                          | 600                  |                                |
| Dimethyl carbamoyl chloride                                 |    | (e)                          | (e)                                 | –                            | –                                   | –                                 | –                    | –                            | –                    |                                |
| Dimethyl-1,2-dibromo-2,2-dichloroethyl phosphate, see Naled |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethyl ether                                              |    | –                            | –                                   | –                            | –                                   | 400                               | 766                  | 500                          | 958                  |                                |
| N,N-Dimethylethylamine                                      |    | –                            | –                                   | –                            | –                                   | 10                                | 30                   | 15                           | 45                   |                                |
| Dimethylethoxy silane                                       |    | 0.5                          | –                                   | 1.5                          | –                                   | –                                 | –                    | –                            | –                    |                                |
| Dimethylformamide                                           | SK | 10                           | 30                                  | –                            | –                                   | SK                                | 10                   | 30                           | 20                   | 2.2                            |
| 2,6-Dimethyl-4-heptanone, see Diisobutyl ketone             |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| 1,1-Dimethyl hydrazine                                      | SK | 0.01 <sup>(e)</sup>          | –                                   | –                            | –                                   | –                                 | carcinogen           | –                            | –                    | 1.7                            |
| Dimethylnitrosoamine, see N-Nitrosodimethylamine            |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                |
| Dimethylphthalate                                           |    | –                            | 5                                   | –                            | –                                   | –                                 | 5                    | –                            | 10                   |                                |
| Dimethyl sulphate                                           | SK | 0.1 <sup>(e)</sup>           | 0.52 <sup>(e)</sup>                 | –                            | –                                   | SK                                | 0.05                 | 0.25                         | –                    |                                |

|                                                                                      |    |      |                   |     |     |    |      |                                                        |     |     |    |
|--------------------------------------------------------------------------------------|----|------|-------------------|-----|-----|----|------|--------------------------------------------------------|-----|-----|----|
| Dinitolmide                                                                          |    | —    | 5                 | —   | —   |    | —    | —                                                      | —   | —   |    |
| Dinitrobenzene (all isomers)                                                         | SK | 0.15 | 1                 | —   | —   | SK | 0.15 | 1                                                      | 0.5 | 3   |    |
| Dinitro- <i>o</i> -cresol                                                            | SK | —    | 0.2               | —   | —   | SK | —    | 0.2                                                    | —   | 0.6 |    |
| 1,2-Dinitroethane, <i>see</i> Ethylene glycol dinitrate                              |    |      |                   |     |     |    |      |                                                        |     |     |    |
| 1,2-Dinitropropane                                                                   |    | —    | —                 | —   | —   | SK | —    | —                                                      | —   | —   |    |
| 3,5-Dinitro- <i>o</i> -toluamide, <i>see</i> Dinitolmide                             |    |      |                   |     |     |    |      |                                                        |     |     |    |
| Dinitrotoluene                                                                       | SK | —    | 0.2               | —   | —   | SK | —    | carcinogen                                             | —   | —   |    |
| Di-nonyl phthalate                                                                   |    | —    | —                 | —   | —   |    | —    | 5                                                      | —   | —   |    |
| Dioxane                                                                              | SK | 20   | —                 | —   | —   | SK | 25   | 90                                                     | 100 | 366 | 24 |
| Dioxathion                                                                           | SK | —    | 0.2               | —   | —   | SK | —    | 0.2                                                    | —   | —   |    |
| Diphenyl, <i>see</i> Biphenyl                                                        |    |      |                   |     |     |    |      |                                                        |     |     |    |
| Diphenylamine                                                                        |    | —    | 10                | —   | —   |    | —    | 10                                                     | —   | 20  |    |
| Diphenyl ether (vapour),<br><i>see</i> Phenyl Ether                                  |    |      |                   |     |     |    |      |                                                        |     |     |    |
| Diphenylmethane diisocyanate, <i>see</i> Isocyanates; Methylene bisphenyl isocyanate |    |      |                   |     |     |    |      |                                                        |     |     |    |
| Diphosphorus pentoxide                                                               |    | —    | —                 | —   | —   |    | —    | —                                                      | —   | 2   |    |
| Dipotassium peroxydisulphate,<br>as S <sub>2</sub> O <sub>8</sub>                    |    | —    | —                 | —   | —   |    | —    | 1                                                      | —   | —   |    |
| Dipropylene glycol methyl ether                                                      | SK | 100  | 606               | 150 | 909 |    | —    | —                                                      | —   | —   |    |
| Dipropyl ketone                                                                      |    | 50   | 233               | —   | —   |    | —    | —                                                      | —   | —   |    |
| Diquat                                                                               |    | —    | 0.5               | —   | —   |    | —    | 0.5                                                    | —   | 1   |    |
| Di-sec-octyl phthalate                                                               |    | —    | 5                 | —   | —   |    | —    | 5                                                      | —   | 10  |    |
| Disodium disulphite                                                                  |    | —    | 5                 | —   | —   |    | —    | 5                                                      | —   | —   |    |
| Disodium peroxydisulphate,<br>as S <sub>2</sub> O <sub>8</sub>                       |    | —    | —                 | —   | —   |    | —    | 1                                                      | —   | —   |    |
| Disodium tetraborate<br>anhydrous                                                    |    | —    | —                 | —   | —   |    | —    | 1                                                      | —   | —   |    |
| decahydrate                                                                          |    | —    | —                 | —   | —   |    | —    | 5                                                      | —   | —   |    |
| pentahydrate                                                                         |    | —    | —                 | —   | —   |    | —    | 1                                                      | —   | —   |    |
| Disulfiram                                                                           |    | —    | 2                 | —   | —   |    | —    | —                                                      | —   | —   |    |
| Disulfoton                                                                           |    | —    | 0.1               | —   | —   |    | —    | 0.1                                                    | —   | 0.3 |    |
| Disulphur dichloride                                                                 |    | —    | —                 | C1  | —   |    | —    | —                                                      | 1   | 5.6 |    |
| Diuron                                                                               |    | —    | 10                | —   | —   |    | —    | 10                                                     | —   | —   |    |
| Divinyl benzene                                                                      |    | 10   | 53                | —   | —   |    | 10   | 54                                                     | —   | —   |    |
| Dusts                                                                                |    |      |                   |     |     |    |      | (S)                                                    |     |     |    |
| Emery                                                                                |    | —    | 10 <sup>(i)</sup> | —   | —   |    | —    | 10 (total<br>inhalable dust)<br>4<br>(respirable dust) | —   | —   |    |
| Endosulfan                                                                           | SK | —    | 0.1               | —   | —   | SK | —    |                                                        | 0.1 | 0.3 |    |
| Endrin                                                                               | SK | —    | 0.1               | —   | —   | SK | —    |                                                        | 0.1 | 0.3 |    |
| Enflurane                                                                            |    | 75   | 566               | —   | —   |    | 50   | 383                                                    | —   | —   |    |

Table 5.12 Cont'd

| Substance                                                           |    | Threshold limit values (USA) |                                     |                           |                                     | Occupational exposure limits (UK) |                      |                           |                      | Air odour threshold (ppm; v/v) |        |
|---------------------------------------------------------------------|----|------------------------------|-------------------------------------|---------------------------|-------------------------------------|-----------------------------------|----------------------|---------------------------|----------------------|--------------------------------|--------|
|                                                                     |    | TWA (ppm) <sup>(a)</sup>     | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL (ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup> (ppm)          | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup> (ppm) | (mg/m <sup>3</sup> ) |                                |        |
| Enzymes, see Subtilisins                                            |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| Epichlorohydrin                                                     | SK | 0.5                          | 1.9                                 | —                         | —                                   | SK MEL                            | 0.5                  | 1.9                       | 1.5                  | 5.8                            | 0.93   |
| EPN                                                                 | SK | —                            | 0.1                                 | —                         | —                                   |                                   | —                    | —                         | —                    | —                              |        |
| 1,2-Epoxypropane, see Propylene oxide                               |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| 2,3-Epoxy-1-propanol, see Glycidol                                  |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| 2,3-Epoxypropyl isopropyl ether                                     |    | 50                           | 240 <sub>(d)</sub>                  | 75                        | 360                                 | 50                                | 240 <sub>(d)</sub>   | 75                        | 360                  |                                |        |
| Ethane                                                              |    |                              |                                     |                           |                                     |                                   |                      |                           |                      | 120 000                        |        |
| Ethanethiol, see Ethyl mercaptan                                    |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| Ethanol, see Ethyl alcohol                                          |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| Ethanolamine                                                        |    | 3                            | 7.5                                 | 6                         | 15                                  | 3                                 | 7.6                  | 6                         | 15                   | 2.6                            |        |
| Ethion                                                              | SK | —                            | 0.4                                 | —                         | —                                   | —                                 | —                    | —                         | —                    | —                              |        |
| 2-Ethoxyethanol (EGEE)                                              | SK | 5                            | 18                                  | —                         | —                                   | SK                                | 10                   | 37 MEL                    | —                    | —                              | 2.7    |
| 2-Ethoxyethyl acetate (EGEEA)                                       | SK | 5                            | 27                                  | —                         | —                                   | SK                                | 10                   | 54 MEL                    | —                    | —                              | 0.056  |
| Ethyl acetate                                                       |    | 400                          | 1440                                | —                         | —                                   |                                   | 400                  | 1460                      | —                    | —                              | 3.9    |
| Ethyl acrylate                                                      |    | 5 <sup>(e)</sup>             | 20 <sup>(e)</sup>                   | 15 <sup>(g)</sup>         | 61 <sup>(g)</sup>                   | SK                                | 5                    | 20                        | 15                   | 60                             | 0.0012 |
| Ethyl alcohol                                                       |    | 1000                         | 1880                                | —                         | —                                   |                                   | 1000                 | 1920                      | —                    | —                              | 84     |
| Ethylamine                                                          |    | 5                            | 9                                   | —                         | —                                   |                                   | 2                    | 3.8                       | 6                    | 11                             | 0.95   |
| Ethyl amyl ketone                                                   |    | 25                           | 131                                 | —                         | —                                   |                                   | 25                   | 133                       | —                    | —                              | 6.0    |
| Ethyl benzene                                                       |    | 100                          | 441                                 | 125                       | 552                                 |                                   | 100                  | 441                       | 125                  | 552                            | 2.3    |
| Ethyl bromide                                                       |    | 5                            | —                                   | —                         | —                                   |                                   | 200                  | 906                       | 250                  | 1130                           | 3.1    |
| Ethyl tert-butyl ether                                              |    | 5                            | —                                   | —                         | —                                   |                                   | —                    | —                         | —                    | —                              |        |
| Ethyl butyl ketone                                                  |    | 50                           | 234                                 | 75                        | 351                                 |                                   | 50                   | 237                       | 100                  | 475                            |        |
| Ethyl chloride                                                      |    | 100                          | —                                   | —                         | —                                   |                                   | 1000                 | 2700                      | 1250                 | 3380                           | 4.2    |
| Ethylchloroformate                                                  |    | —                            | —                                   | —                         | —                                   |                                   | 1                    | 4.4                       | —                    | —                              |        |
| Ethyl cyanoacrylate                                                 |    | 0.2                          | —                                   | —                         | —                                   |                                   | —                    | —                         | —                    | 0.3                            | 1.5    |
| Ethylene                                                            |    |                              | <sub>(d)</sub>                      |                           |                                     |                                   |                      |                           |                      |                                | 290    |
| Ethylene chlorohydrin                                               | SK | —                            | —                                   | C1                        | —                                   | SK                                | —                    | —                         | 1                    | 3.4                            |        |
| Ethylenediamine                                                     |    | 10                           | 25                                  | —                         | —                                   |                                   | 10                   | 25                        | —                    | —                              | 1.0    |
| Ethylene dibromide                                                  | SK | <sub>(e)</sub>               | <sub>(e)</sub>                      | —                         | —                                   | SK                                | 0.5                  | 4 MEL                     | —                    | —                              | 2.5    |
| Ethylene dichloride                                                 |    | 10                           | 40                                  | —                         | —                                   |                                   | 5                    | 21                        | —                    | —                              | 88     |
| Ethylene glycol, vapour and mist                                    |    | —                            | —                                   | —                         | C100                                | }                                 | —                    | 10<br>particulate         | —                    | —                              |        |
|                                                                     |    |                              |                                     |                           |                                     |                                   |                      | 60<br>vapour              | —                    | 125                            |        |
| Ethylene glycol dinitrate                                           | SK | 0.05                         | 0.31                                | —                         | —                                   | SK                                | 0.2                  | 1.3                       | 0.2                  | 1.3                            |        |
| Ethylene glycol methyl ether acetate,<br>see 2-Methoxyethyl acetate |    |                              |                                     |                           |                                     |                                   |                      |                           |                      |                                |        |
| Ethylene oxide                                                      |    | 1 <sup>(e)</sup>             | 1.8 <sup>(e)</sup>                  | —                         | —                                   | SK                                | 5                    | 9.2 MEL                   | —                    | —                              | 430    |
| Ethylene imine                                                      | SK | 0.5                          | 0.88                                | —                         | —                                   | SK                                |                      |                           | carcinogen           |                                |        |

|                                                       |    |      |      |                     |      |     |      |                                                         |      |         |         |
|-------------------------------------------------------|----|------|------|---------------------|------|-----|------|---------------------------------------------------------|------|---------|---------|
| Ethyl ether                                           |    | 400  | 1210 | 500                 | 1520 |     | 400  | 1230                                                    | 500  | 1540    | 8.9     |
| Ethyl formate                                         |    | 100  | 303  | —                   | —    |     | 100  | 308                                                     | 150  | 462     | 31      |
| 2-Ethylhexyl chloroformate                            |    | —    | —    | —                   | —    |     | 1    | 7.9                                                     | —    | —       |         |
| Ethylidene chloride, see<br>1,1-Dichloroethane        |    |      |      |                     |      |     |      |                                                         |      |         |         |
| Ethylidene norbornene                                 |    | —    | —    | C5                  | —    |     |      |                                                         |      |         | 0.014   |
| Ethyl mercaptan                                       |    | 0.5  | 1.3  | —                   | —    |     | 0.5  | 1.3                                                     | 2    | 5.2     | 0.00076 |
| N-Ethylmorpholine                                     | SK | 5    | 24   | —                   | —    | SK  | 5    | 24                                                      | 20   | 96      | 1.4     |
| Ethyl silicate                                        |    | 10   | 85   | —                   | —    |     | 10   | 87                                                      | 30   | 260     | 17      |
| Fenamiphos                                            | SK | —    | 0.1  | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Fenchlorphos, see Ronnel                              |    |      |      |                     |      |     |      |                                                         |      |         |         |
| Fensulfothion                                         |    | —    | 0.1  | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Fenthion                                              | SK | —    | 0.2  | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Ferbam                                                |    | —    | 10   | —                   | —    |     | —    | 10                                                      | —    | 20      |         |
| Ferrocene                                             |    | —    | 10   | —                   | —    |     | —    | 10                                                      | —    | 20      |         |
| Ferrous foundry particulate                           |    |      |      |                     |      |     |      |                                                         |      |         |         |
| total inhalable dust                                  |    | —    | —    | —                   | —    |     | —    | 10                                                      | —    | —       |         |
| respirable dust                                       |    | —    | —    | —                   | —    |     | —    | 4                                                       | —    | —       |         |
| Ferrovanadium dust                                    |    | —    | 1    | —                   | 3    |     |      |                                                         |      |         |         |
| Fibrous glass dust                                    |    | —    | 10   | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Flour dust                                            |    | —    | 5    | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Fluorides as F                                        |    | —    | 2.5  | —                   | —    |     | —    | 2.5                                                     | —    | —       |         |
| Fluorine                                              |    | 1    | 1.6  | 2                   | 3.1  |     | —    | —                                                       | 1    | 1.6     | 0.14    |
| Fluorotrichloromethane, see<br>Trichlorofluoromethane |    |      |      |                     |      |     |      |                                                         |      |         |         |
| Fonofos                                               | SK | —    | 0.1  | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Formaldehyde                                          |    | —    | —    | C0.3 <sup>(e)</sup> | —    |     | 2    | 2.5 MEL                                                 | 2    | 2.5 MEL | 0.83    |
| Formamide                                             | SK | 10   | 18   | —                   | —    |     | 20   | 37                                                      | 30   | 56      |         |
| Formic acid                                           |    | 5    | 9.4  | 10                  | 19   |     | 5    | 9.6                                                     | —    | —       | 49      |
| Furfural                                              | SK | 2    | 7.9  | —                   | —    | SK  | 2    | 8                                                       | 5    | 20      | 0.078   |
| Furfuryl alcohol                                      | SK | 10   | 40   | 15                  | 60   | SK  | 5    | 20                                                      | 15   | 60      | 8.0     |
| Gasoline                                              |    | 300  | 890  | 500                 | 1480 |     | —    | —                                                       | —    | —       |         |
| Germanium tetrahydride                                |    | 0.2  | 0.63 | —                   | —    |     | 0.2  | 0.6                                                     | 0.6  | 1.9     |         |
| Glass, fibrous or dust, see Fibrous<br>glass dust     |    |      |      |                     |      |     |      |                                                         |      |         |         |
| Glutaraldehyde                                        |    | —    | —    | C0.05               | —    | SEN | 0.05 | 0.2                                                     | 0.05 | 0.2     |         |
| Glycerin mist                                         |    | —    | 10   | —                   | —    |     | —    | 10                                                      | —    | —       |         |
| Glycidol                                              |    | 2    | —    | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Glycol monoethyl ether, see<br>2-Ethoxyethanol        |    |      |      |                     |      |     |      |                                                         |      |         |         |
| Glycerol trinitrate                                   | SK | 0.05 | —    | —                   | —    | SK  | 0.2  | 1.9                                                     | 0.2  | 1.9     |         |
| Grain dust (oat, wheat, barley)                       |    | —    | 4    | —                   | —    |     | —    | —                                                       | —    | —       |         |
| Graphite, all forms<br>except graphite fibres         |    | —    | 2    | —                   | —    |     | —    | 10 (total<br>(inhalable dust)<br>4<br>(respirable dust) | —    | —       |         |

Table 5.12 Cont'd

| Substance                                              |    | Threshold limit values (USA) |                                     |                              |                                     | Occupational exposure limits (UK)                                                                                                                                                                                                                                                             |                      |                              |                      | Air odour threshold<br>(ppm; v/v) |
|--------------------------------------------------------|----|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|------------------------------|----------------------|-----------------------------------|
|                                                        |    | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)                                                                                                                                                                                                                                                                   | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                   |
| Gypsum, see Calcium sulphate                           |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hafnium                                                |    | —                            | 0.5                                 | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | 0.5                  | —                            | 1.5                  |                                   |
| Halothane                                              |    | 50                           | 404 <sup>(f)</sup>                  | —                            | —                                   | 10                                                                                                                                                                                                                                                                                            | 82 <sup>(f)</sup>    | —                            | —                    | 33                                |
| Helium                                                 |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Heptachlor                                             | SK | —                            | 0.5                                 | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Heptane ( <i>n</i> -Heptane)                           |    | 400                          | 1640                                | 500                          | 2050                                | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    | 150                               |
| 2-Heptanone, see Methyl <i>n</i> -amyl ketone          |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| 3-Heptanone, see Ethyl butyl ketone                    |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hexachlorobenzene                                      |    | —                            | 0.002                               | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Hexachlorobutadiene                                    | SK | 0.02 <sup>(e)</sup>          | 0.21 <sup>(e)</sup>                 | —                            | —                                   |                                                                                                                                                                                                                                                                                               | —                    | —                            | —                    |                                   |
| Hexachlorocyclohexane, see Lindane                     |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hexachlorocyclopentadiene                              |    | 0.01                         | 0.11                                | —                            | —                                   | <div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 3em; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;"> 5<br/><br/>50<br/>(vapour)<br/>10 (total<br/>inhalable dust)<br/>4<br/>(respirable dust) </div> </div> | —                    | —                            | —                    | 0.030                             |
|                                                        |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               | —                    | —                            | —                    | 0.15                              |
| Hexachloroethane                                       |    | 1                            | 9.7                                 | —                            | —                                   |                                                                                                                                                                                                                                                                                               | —                    | —                            | —                    |                                   |
|                                                        |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               | —                    | —                            | —                    |                                   |
| Hexachloronaphthalene                                  | SK | —                            | 0.2                                 | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Hexafluoroacetone                                      | SK | 0.1                          | 0.68                                | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Hexahydro-1,3,5-trinitro-1,3,5-triazine, see Cyclonite |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hexamethylene diisocyanate                             |    | 0.005 <sup>(e)</sup>         | 0.034 <sup>(e)</sup>                | —                            | —                                   | see Isocyanates                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hexamethyl phosphoramide                               | SK | —                            | —                                   | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Hexane ( <i>n</i> -hexane)                             |    | 50                           | 176                                 | —                            | —                                   | 20                                                                                                                                                                                                                                                                                            | 72                   | —                            | —                    | 130                               |
| Other isomers                                          |    | 500                          | 1760                                | 1000                         | 3500                                |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| Hexanediamine                                          |    | 0.5                          | —                                   | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| 1,6-Hexanolactam, see Caprolactam                      |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| 2-Hexanone, see Methyl <i>n</i> -butyl ketone          |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| 1-Hexene                                               |    | 30                           | —                                   | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |
| Hexone, see Methyl isobutyl ketone                     |    |                              |                                     |                              |                                     |                                                                                                                                                                                                                                                                                               |                      |                              |                      |                                   |
| sec-Hexyl acetate                                      |    | 50                           | 295                                 | —                            | —                                   | SK                                                                                                                                                                                                                                                                                            | 50                   | 205                          | 75                   | 300                               |
| Hexylene glycol                                        |    | —                            | —                                   | C25                          | —                                   | SK                                                                                                                                                                                                                                                                                            | 25                   | 123                          | 25                   | 123                               |
| Hydrazine                                              | SK | 0.01                         | —                                   | —                            | —                                   | SK                                                                                                                                                                                                                                                                                            | 0.02                 | 0.03                         | 0.1                  | 0.13 MEL 3.7                      |
| Hydrazoic acid, vapour                                 |    | —                            | —                                   | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | 0.1                          | 0.18                 |                                   |
| Hydrogen                                               |    |                              | (d)                                 |                              |                                     |                                                                                                                                                                                                                                                                                               | (d)                  |                              |                      |                                   |
| Hydrogenated terphenyls (non irradiated)               |    | 0.5                          | 4.9                                 | —                            | —                                   | —                                                                                                                                                                                                                                                                                             | —                    | —                            | —                    |                                   |



|                                                                                     |                |       |       |      |                 |      |          |      |          |
|-------------------------------------------------------------------------------------|----------------|-------|-------|------|-----------------|------|----------|------|----------|
| Hydrogen bromide                                                                    | —              | —     | C3    | C9.9 | —               | —    | 3        | 10   | 2.0      |
| Hydrogen chloride                                                                   | —              | —     | C5    | C7.5 | 1               | 2    | 5        | 8    | 0.77     |
| Hydrogen cyanide and cyanide salts<br>(excluding cyanogen and cyanogen<br>chloride) |                |       |       |      |                 |      |          |      |          |
| Hydrogen cyanide                                                                    | —              | C4.7  | —     | —    | —               |      | MEL 10   | 11   |          |
| Calcium cyanide                                                                     | —              | —     | —     | C5   | }               |      |          |      |          |
| Potassium cyanide                                                                   | —              | —     | —     | C5   |                 | 5    | —        | —    |          |
| Sodium cyanide                                                                      | —              | —     | —     | C5   |                 |      |          |      |          |
| Hydrogen fluoride as F                                                              | —              | —     | C3    | —    | —               | —    | 3        | 2.5  | 0.042    |
| Hydrogen peroxide                                                                   | 1              | 1.4   | —     | —    | 1               | 1.4  | 2        | 2.8  | 0.30     |
| Hydrogen selenide as Se                                                             | 0.05           | 0.16  | —     | —    | 0.05            | 0.17 | —        | —    | 0.0081   |
| Hydrogen sulphide                                                                   | 10             | 14    | 15    | 21   | 10              | 14   | 15       | 21   |          |
| Hydroquinone                                                                        | —              | 2     | —     | —    | —               | 2    | —        | 4    |          |
| 4-Hydroxy-4-methyl-2-pentanone, see<br>Diacetone alcohol                            |                |       |       |      |                 |      |          |      |          |
| 2-Hydroxypropyl acrylate                                                            | 0.5            | 2.8   | —     | —    | SK              | 0.5  | 2.7      | —    |          |
| Indene                                                                              | 10             | 48    | —     | —    |                 | 10   | 48       | 15   | 72       |
| Indium and compounds as In                                                          | —              | 0.1   | —     | —    |                 | —    | 0.1      | —    | 0.3      |
| Iodine                                                                              | —              | —     | C0.1  | —    | —               | —    | 0.1      | 1    |          |
| Iodoform                                                                            | 0.6            | 10    | —     | —    | 0.6             | 9.8  | 1        | 16   | 0.005    |
| Iron oxide dust + fume (Fe <sub>2</sub> O <sub>3</sub> ) as Fe                      | <sup>(1)</sup> | 5     | —     | —    | —               | 5    | —        | 10   |          |
| Iron pentacarbonyl as Fe                                                            | 0.1            | 0.23  | 0.2   | 0.45 | 0.01            | 0.08 | —        | —    |          |
| Iron salts, soluble, as Fe                                                          | —              | 1     | —     | —    | —               | 1    | —        | 2    |          |
| Isoamyl acetate                                                                     | 50             | 266   | 100   | 532  | 50              | 270  | 100      | 541  | 0.025    |
| Isoamyl alcohol                                                                     | 100            | 361   | 125   | 452  | 100             | 366  | 125      | 458  | 0.042    |
| Isobutyl acetate                                                                    | 150            | 713   | —     | —    | 150             | 724  | 187      | 903  | 0.64     |
| Isobutyl alcohol                                                                    | SK             | 50    | 152   | —    | 50              | 154  | 75       | 231  | 1.6      |
| Isocyanates, all, as-NCO                                                            | —              | —     | —     | —    | SK              | —    | 0.02 MEL | —    | 0.07 MEL |
| Isofluorane                                                                         | —              | —     | —     | —    | 50              | 383  | —        | —    |          |
| Isooctyl alcohol                                                                    | SK             | 50    | 266   | —    | 50              | 270  | —        | —    |          |
| Isopentyl acetate                                                                   | —              | —     | —     | —    | 50              | 270  | 100      | 541  |          |
| Isophorone                                                                          | —              | —     | C5    | C28  | —               | —    | 5        | 29   | 0.20     |
| Isophorone diisocyanate                                                             | SK             | 0.005 | 0.045 | —    | see Isocyanates |      |          |      |          |
| Isopropoxyethanol                                                                   | 25             | 106   | —     | —    | —               | —    | —        | —    |          |
| Isopropyl acetate                                                                   | 250            | 1040  | 310   | 1290 | —               | —    | 200      | 849  | 2.7      |
| Isopropyl alcohol                                                                   | 400            | 983   | 500   | 1230 | SK              | 400  | 999      | 500  | 1250     |
| Isopropylamine                                                                      | 5              | 12    | 10    | 24   | —               | —    | —        | —    | 1.2      |
| N-Isopropylaniline                                                                  | SK             | 2     | 11    | —    | —               | —    | —        | —    |          |
| Isopropyl chloroformate                                                             | —              | —     | —     | —    | 1               | 5    | —        | —    |          |
| Isopropyl ether                                                                     | 250            | 1040  | 310   | 1300 | 250             | 1060 | 310      | 1310 | 0.017    |
| Isopropyl glycidyl ether (IGE), see<br>2,3-Epoxypropyl isopropyl ether              |                |       |       |      |                 |      |          |      |          |
| Kaolin                                                                              | —              | 2     | —     | —    | —               | 2    | —        | —    |          |
| Ketene                                                                              | 0.5            | 0.86  | 1.5   | 2.6  | 0.5             | 0.87 | 1.5      | 2.6  |          |

Table 5.12 Cont'd

| Substance                                        | Threshold limit values (USA) |                                                         |                              |                                     | Occupational exposure limits (UK) |                              |                              |                      | Air odour threshold<br>(ppm; v/v) |
|--------------------------------------------------|------------------------------|---------------------------------------------------------|------------------------------|-------------------------------------|-----------------------------------|------------------------------|------------------------------|----------------------|-----------------------------------|
|                                                  | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup>                     | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> )         | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                   |
| Lead, inorganic dusts and fumes,<br>as Pb        | –                            | 0.05                                                    | –                            | –                                   | (k)                               |                              |                              |                      |                                   |
| lead alkyls                                      |                              |                                                         |                              |                                     | (k)                               |                              |                              |                      |                                   |
| Lead arsenate as PbHAsO <sub>4</sub>             | –                            | 0.15                                                    | –                            | –                                   |                                   |                              |                              |                      |                                   |
| Lead chromate as Cr                              | –                            | 0.05 as Pb <sup>(e)</sup><br>0.012 as Cr <sup>(e)</sup> |                              |                                     |                                   |                              |                              |                      |                                   |
| Limestone, see Calcium carbonate                 |                              |                                                         |                              |                                     |                                   |                              |                              |                      |                                   |
| Lindane                                          | SK                           | 0.5                                                     | –                            | –                                   | SK                                | 0.1                          | –                            | –                    |                                   |
| Lithium hydride                                  | –                            | 0.025                                                   | –                            | –                                   | –                                 | 0.025                        | –                            | –                    |                                   |
| Lithium hydroxide                                | –                            | –                                                       | –                            | –                                   | –                                 | –                            | –                            | 1                    |                                   |
| LPG (Liquefied petroleum gas)                    | 1000                         | 1800                                                    | –                            | –                                   | 1000                              | 1750                         | 1250                         | 2180                 |                                   |
| Magnesite                                        | –                            | 10 <sup>(l)</sup>                                       | –                            | –                                   | –                                 | 10 (total<br>inhalable dust) | –                            | –                    |                                   |
|                                                  |                              |                                                         |                              |                                     |                                   | 4<br>(respirable dust)       | –                            | –                    |                                   |
|                                                  |                              |                                                         |                              |                                     |                                   | 4 (fume,<br>respirable dust) | –                            | 10                   |                                   |
| Magnesium oxide fume                             | –                            | 10                                                      | –                            | –                                   | –                                 | 10 (total<br>inhalable dust) | –                            | –                    |                                   |
| Malathion                                        | SK                           | 10                                                      | –                            | –                                   | SK                                | 10                           | –                            | –                    |                                   |
| Maleic anhydride                                 | 0.1                          | –                                                       | –                            | –                                   | –                                 | 1                            | –                            | 3 MEL                | 0.32                              |
| Manganese as Mn                                  |                              |                                                         |                              |                                     |                                   |                              |                              |                      |                                   |
| Dust and compounds                               | –                            | –                                                       | –                            | –                                   | –                                 | 5                            | –                            | –                    |                                   |
| Fume                                             | –                            | –                                                       | –                            | 3                                   | –                                 | 1                            | –                            | 3                    |                                   |
| Elemental and inorganic compounds                | –                            | 0.2                                                     | –                            | –                                   | –                                 | –                            | –                            | –                    |                                   |
| Manganese cyclopenta-dienyl<br>tricarbonyl as Mn | SK                           | 0.1                                                     | –                            | –                                   | SK                                | 0.1                          | –                            | 0.3                  |                                   |
| Manganese methyl-pentadienyl<br>tricarbonyl      | –                            | –                                                       | –                            | –                                   | SK                                | 0.2                          | –                            | 0.6                  |                                   |
| Manganese tetroxide                              | –                            | –                                                       | –                            | –                                   | –                                 | 1                            | –                            | –                    |                                   |
| Man-made mineral fibre                           | –                            | –                                                       | –                            | –                                   | –                                 | 5 MEL                        | –                            | –                    |                                   |
| Marble, see Calcium carbonate                    |                              |                                                         |                              |                                     |                                   |                              |                              |                      |                                   |
| Mercaptoacetic acid, see<br>Thioglycolic acid    |                              |                                                         |                              |                                     |                                   |                              |                              |                      |                                   |
| Mequinol (INN)                                   | –                            | 5                                                       | –                            | –                                   | –                                 | 5                            | –                            | –                    |                                   |
| Mercury, as Hg                                   |                              |                                                         |                              |                                     |                                   |                              |                              |                      |                                   |
| Alkyl compounds                                  | –                            | 0.01                                                    | –                            | 0.03                                | –                                 | 0.01                         | –                            | 0.03                 |                                   |
| Aryl compounds                                   | –                            | 0.1                                                     | –                            | –                                   | –                                 | –                            | –                            | –                    |                                   |

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Table 5.12 Cont'd

| Substance                                                       |    | Threshold limit values (USA) |                                     |                              |                                     | Occupational exposure limits (UK) |                      |                              |                      | Air odour<br>threshold<br>(ppm; v/v) |
|-----------------------------------------------------------------|----|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----------------------------------|----------------------|------------------------------|----------------------|--------------------------------------|
|                                                                 |    | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                      |
| 4-4'-Methylene<br>bis(2-chloroaniline)                          | SK | 0.01 <sup>(e)</sup>          | 0.11 <sup>(e)</sup>                 | —                            | —                                   | —                                 | 0.005                | —                            | —                    |                                      |
| Methylene bis(4-cyclo-<br>hexylisocyanate)                      |    | 0.005                        | 0.054                               | —                            | —                                   | see Isocyanates                   |                      |                              |                      |                                      |
| 4,4'-Methylenedianiline                                         | SK | 0.1 <sup>(e)</sup>           | 0.81 <sup>(e)</sup>                 | —                            | —                                   | 0.01                              | 0.08                 | —                            | —                    |                                      |
| Methyl ethyl ketone (MEK)                                       |    | 200                          | 590                                 | 300                          | 885                                 | 200                               | 600                  | 300                          | 899                  | 5.4                                  |
| Methyl ethyl ketone peroxide                                    |    | —                            | —                                   | C0.2                         | —                                   | —                                 | —                    | 0.2                          | 1.5                  |                                      |
| Methyl formate                                                  |    | 100                          | 246                                 | 150                          | 368                                 | 100                               | 250                  | 150                          | 375                  | 600                                  |
| 5-Methyl-3-heptanone, see Ethyl<br>amyl ketone                  |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |
| 5-Methylhexan-2-one                                             |    | —                            | —                                   | —                            | —                                   | 50                                | 237                  | 100                          | 475                  |                                      |
| Methyl hydrazine                                                | SK | 0.1                          | —                                   | —                            | —                                   | —                                 | —                    | —                            | —                    | 1.7                                  |
| Methyl iodide                                                   | SK | 2 <sup>(e)</sup>             | 12 <sup>(e)</sup>                   | —                            | —                                   | SK                                | 2                    | 12                           | —                    |                                      |
| Methyl isoamyl ketone                                           |    | 50                           | 234                                 | —                            | —                                   | 50                                | 237                  | 100                          | 475                  | 0.012                                |
| Methyl isobutyl carbinol                                        | SK | 25                           | 104                                 | 40                           | 167                                 | SK                                | 25                   | 106                          | 40                   | 0.070                                |
| Methyl isobutyl ketone                                          |    | 50                           | 205                                 | 75                           | 307                                 | SK                                | 50                   | 208                          | 100                  | 0.68                                 |
| Methyl isocyanate                                               | SK | 0.02                         | 0.047                               | —                            | —                                   | see Isocyanates                   |                      |                              |                      | 2.1                                  |
| Methyl isopropyl ketone                                         |    | 200                          | 705                                 | —                            | —                                   | —                                 | —                    | —                            | —                    | 1.9                                  |
| Methyl mercaptan                                                |    | 0.5                          | 0.98                                | —                            | —                                   | 0.5                               | 1                    | —                            | —                    | 0.0016                               |
| Methyl methacrylate                                             |    | 50                           | 208                                 | 100                          | 416                                 | 50                                | 208                  | 100                          | 416                  | 0.083                                |
| Methyl parathion                                                | SK | —                            | 0.2                                 | —                            | —                                   | SK                                | —                    | 0.2                          | —                    | 0.6                                  |
| 2-Methylpentane-2,4-diol                                        |    | —                            | —                                   | —                            | —                                   | 25                                | 125                  | 25                           | 125                  |                                      |
| 4-Methylpentan-2-ol                                             |    | —                            | —                                   | —                            | —                                   | SK                                | 25                   | 100                          | 40                   | 170                                  |
| 4-Methylpentan-2-one                                            |    | —                            | —                                   | —                            | —                                   | SK                                | 50                   | 205                          | 100                  | 416                                  |
| 4-Methylpent-3-en-2-one                                         |    | —                            | —                                   | —                            | —                                   | 15                                | 60                   | 25                           | 100                  |                                      |
| 2-Methylpropan-1-ol                                             |    | —                            | —                                   | —                            | —                                   | 50                                | 150                  | 75                           | 225                  |                                      |
| Methyl propyl ketone                                            |    | 200                          | 705                                 | 250                          | 881                                 | 200                               | 716                  | 250                          | 895                  | 11                                   |
| 1-Methyl-2-pyrrolidone                                          |    | —                            | —                                   | —                            | —                                   | 25                                | 103                  | 75                           | 309                  |                                      |
| Methyl silicate                                                 |    | 1                            | 6.3                                 | —                            | —                                   | 1                                 | 6.3                  | 5                            | 32                   |                                      |
| Methyl styrene (all isomers except<br>$\alpha$ -methyl styrene) |    | —                            | —                                   | —                            | —                                   | 100                               | 491                  | 150                          | 736                  |                                      |
| $\alpha$ -Methyl styrene                                        |    | 50                           | 242                                 | 100                          | 483                                 | —                                 | —                    | 100                          | 491                  | 0.29                                 |
| N-Methyl-N,2,4,6-tetranitroaniline                              |    | —                            | —                                   | —                            | —                                   | —                                 | 1.5                  | —                            | 3                    |                                      |
| Methyl vinyl ketone                                             |    | —                            | —                                   | C0.2                         | —                                   | —                                 | —                    | —                            | —                    |                                      |
| Metribuzin                                                      |    | —                            | 5                                   | —                            | —                                   | —                                 | —                    | —                            | —                    |                                      |
| Mevinphos                                                       | SK | 0.01                         | 0.09                                | 0.03                         | 0.27                                | SK                                | 0.01                 | 0.1                          | 0.03                 | 0.28                                 |
| Mica                                                            |    | —                            | 3<br>(respirable dust)              | —                            | —                                   | }                                 | —                    | 10 (total<br>inhalable dust) | —                    | —                                    |
|                                                                 |    |                              |                                     |                              |                                     |                                   | —                    | 0.8<br>(respirable dust)     | —                    | —                                    |
|                                                                 |    |                              |                                     |                              |                                     |                                   |                      |                              |                      |                                      |

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Table 5.12 Cont'd

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Table 5.12 Cont'd

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|                                       |      |                     |    |    |     |     |                   |     |       |       |
|---------------------------------------|------|---------------------|----|----|-----|-----|-------------------|-----|-------|-------|
| Quinone                               | 0.1  | 0.44                | —  | —  |     | 0.1 | 0.4               | 0.3 | 1.3   | 0.084 |
| RDX, see Cyclonite                    |      |                     |    |    |     |     |                   |     |       |       |
| Resorcinol                            | 10   | 45                  | 20 | 90 |     | 10  | 46                | 20  | 92    |       |
| Rhodium                               |      |                     |    |    |     |     |                   |     |       |       |
| Metal                                 | —    | 1                   | —  | —  |     | —   | 0.1               | —   | 0.3   |       |
|                                       |      |                     |    |    |     |     | (Fume and dust)   |     |       |       |
| Insoluble compounds as Rh             | —    | 1                   | —  | —  |     | —   | —                 | —   | —     |       |
| Soluble compounds as Rh               | —    | 0.01                | —  | —  |     | —   | 0.001             | —   | 0.003 |       |
| Ronnel                                | —    | 10                  | —  | —  |     | —   | 10                | —   | —     |       |
| Rosin core solder, pyrolysis products | —    | 0.1                 | —  | —  | SEN | —   | 0.05 MEL          | —   | 0.15  |       |
| Rotenone (commercial)                 | —    | 5                   | —  | —  |     | —   | 5                 | —   | 10    |       |
|                                       |      |                     |    |    |     | {   | 10 (total         | —   | —     |       |
| Rouge                                 | —    | 10 <sup>(f)</sup>   | —  | —  |     | {   | inhalable dust)   | —   | —     |       |
|                                       |      |                     |    |    |     | {   | 4                 | —   | —     |       |
|                                       |      |                     |    |    |     | {   | (respirable dust) | —   | —     |       |
| Rubber fume                           | —    | —                   | —  | —  |     | —   | 0.6 MEL           | —   | —     |       |
| Rubber process dust                   | —    | —                   | —  | —  |     | —   | 6 MEL             | —   | —     |       |
| Rubber solvent (naphtha)              | 400  | 1590                | —  | —  |     | —   | —                 | —   | —     |       |
|                                       |      |                     |    |    |     |     | (except           | —   | —     |       |
| Selenium and compounds as Se          | —    | 0.2                 | —  | —  |     | 0.1 | hydrogen          | —   | —     |       |
|                                       |      |                     |    |    |     |     | selenide)         | —   | —     |       |
| Selenium hexafluoride as Se           | 0.05 | 0.16                | —  | —  |     | —   | —                 | —   | —     |       |
| Sesone                                | —    | 10                  | —  | —  |     | —   | 10                | —   | 20    |       |
| Silane, see Silicon tetrahydride      |      |                     |    |    |     |     |                   |     |       |       |
| Silica, Amorphous                     |      |                     |    |    |     |     |                   |     |       |       |
| Total inhalable dust                  | —    | 10 <sup>(f)</sup>   | —  | —  |     | —   | 6                 | —   | —     |       |
| Respirable dust                       | —    | 3 <sup>(f)</sup>    | —  | —  |     | —   | 2.4               | —   | —     |       |
| Precipitated                          | —    | 10                  | —  | —  |     | —   | —                 | —   | —     |       |
| Silica fume (Respirable)              | —    | 2                   | —  | —  |     | —   | —                 | —   | —     |       |
| Silica fused (Respirable)             | —    | 0.1                 | —  | —  |     | —   | 0.08              | —   | —     |       |
| Silica, Crystalline (Respirable)      |      |                     |    |    |     |     |                   |     |       |       |
| Cristobalite                          | —    | 0.05                | —  | —  | }   |     |                   |     |       |       |
| Quartz                                | —    | 0.05 <sup>(e)</sup> | —  | —  |     |     |                   |     |       |       |
| Tridymite                             | —    | 0.05                | —  | —  |     |     |                   |     |       |       |
| Tripoli                               | —    | 0.1                 | —  | —  |     |     |                   |     |       |       |
|                                       |      |                     |    |    |     |     | 0.3               | —   | —     |       |
|                                       |      |                     |    |    |     | {   | 10 (total         | —   | —     |       |
| Silicon                               | —    | 10 <sup>(f)</sup>   | —  | —  |     | {   | inhalable dust)   | —   | —     |       |
|                                       |      |                     |    |    |     | {   | 4                 | —   | —     |       |
|                                       |      |                     |    |    |     | {   | (respirable dust) | —   | —     |       |
|                                       |      |                     |    |    |     | {   | 10 (total         | —   | —     |       |
| Silicon carbide                       | —    | 10 <sup>(f)</sup>   | —  | —  |     | {   | inhalable dust)   | —   | —     |       |
|                                       |      |                     |    |    |     | {   | 4                 | —   | —     |       |
|                                       |      |                     |    |    |     | {   | (respirable dust) | —   | —     |       |
| Silicon tetrahydride                  | 5    | 6.6                 | —  | —  |     | 0.5 | 0.67              | 1   | 1.3   |       |

Table 5.12 Cont'd

| Substance                                                        | Threshold limit values (USA) |                                     |                           |                                     | Occupational exposure limits (UK)                                                                                                                                                                                                                                    |                      |                           |                      | Air odour threshold (ppm; v/v) |
|------------------------------------------------------------------|------------------------------|-------------------------------------|---------------------------|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------|----------------------|--------------------------------|
|                                                                  | TWA (ppm) <sup>(a)</sup>     | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL (ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup> (ppm)                                                                                                                                                                                                                                             | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup> (ppm) | (mg/m <sup>3</sup> ) |                                |
| Silver                                                           |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Metal                                                            | —                            | 0.1                                 | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 0.1                  | —                         | —                    |                                |
| Compounds as Ag                                                  | —                            | 0.01                                | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 0.01                 | —                         | —                    |                                |
| Soapstone                                                        |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Respirable dust                                                  | —                            | 3                                   | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Total dust                                                       | —                            | 6 <sup>(i)</sup>                    | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Sodium azide                                                     |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| as sodium azide                                                  | —                            | —                                   | —                         | C0.29                               | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    | 0.3                            |
| as hydrazoic acid vapour                                         | —                            | —                                   | C0.11                     | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Sodium bisulphite                                                | —                            | 5                                   | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 5                    | —                         | —                    |                                |
| Sodium 2,4-dichloro-phenoxyethyl sulphate, see Sesone            |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Sodium fluoroacetate SK                                          | —                            | 0.05                                | —                         | 0.15                                | SK                                                                                                                                                                                                                                                                   | —                    | 0.05                      | —                    | 0.15                           |
| Sodium hydroxide                                                 | —                            | —                                   | —                         | C2                                  | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    | 2                              |
| Sodium metabisulphite, see Disodium disulphite                   |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Starch                                                           | —                            | 10                                  | —                         | —                                   | <div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 2em; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;"> — 10 (total<br/>inhalable dust)<br/>— 4<br/>— (respirable dust) </div> </div> | —                    | —                         | —                    |                                |
|                                                                  |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Stearates                                                        | —                            | 10                                  | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Stibine, see Antimony hydride                                    |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Stoddard solvent                                                 | 100                          | 525                                 | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Strontium chromate                                               | —                            | 0.0005 <sup>(e)</sup>               | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Strychnine                                                       | —                            | 0.15                                | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 0.15                 | —                         | —                    | 0.45                           |
| Styrene, monomer SK                                              | 20                           | —                                   | 40                        | —                                   | 100                                                                                                                                                                                                                                                                  | 430 MEL              | 250                       | 1080 MEL             | 0.32                           |
| Subtilisin (proteolytic enzymes as 100% pure crystalline enzyme) | —                            | —                                   | —                         | C0.00006                            | —                                                                                                                                                                                                                                                                    | 0.00006              | —                         | —                    | 0.00006                        |
| Sucrose                                                          | —                            | 10                                  | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 10                   | —                         | —                    | 20                             |
| Sulfotep SK                                                      | —                            | 0.2                                 | —                         | —                                   | SK                                                                                                                                                                                                                                                                   | —                    | 0.2                       | —                    | —                              |
| Sulfometuron methyl                                              | —                            | 5                                   | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Sulphur dioxide                                                  | 2                            | 5.2                                 | 5                         | 13                                  | 2                                                                                                                                                                                                                                                                    | 5                    | 5                         | 13                   | 1.1                            |
| Sulphur hexafluoride                                             | 1000                         | 5970                                | —                         | —                                   | 1000                                                                                                                                                                                                                                                                 | 6070                 | 1250                      | 7590                 |                                |
| Sulphuric acid                                                   | —                            | 1 <sup>(e)</sup>                    | —                         | 3                                   | —                                                                                                                                                                                                                                                                    | 1                    | —                         | —                    |                                |
| Sulphur monochloride, see Disulphur dichloride                   |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| Sulphur pentafluoride                                            | —                            | —                                   | C0.01                     | —                                   | 0.025                                                                                                                                                                                                                                                                | 0.25                 | 0.075                     | —                    | 0.79                           |
| Sulphur tetrafluoride                                            | —                            | —                                   | C0.1                      | —                                   | 0.1                                                                                                                                                                                                                                                                  | 0.4                  | 0.3                       | —                    | 1.2                            |
| Sulphuryl fluoride                                               | 5                            | 21                                  | 10                        | 42                                  | 5                                                                                                                                                                                                                                                                    | 21                   | 10                        | —                    | 42                             |
| Sulprofos                                                        | —                            | 1                                   | —                         | —                                   | —                                                                                                                                                                                                                                                                    | —                    | —                         | —                    |                                |
| Systox, see Demeton                                              |                              |                                     |                           |                                     |                                                                                                                                                                                                                                                                      |                      |                           |                      |                                |
| 2,4,5-T                                                          | —                            | 10                                  | —                         | —                                   | —                                                                                                                                                                                                                                                                    | 10                   | —                         | —                    | 20                             |

|                                                |      |                      |       |     |     |                     |       |      |      |      |
|------------------------------------------------|------|----------------------|-------|-----|-----|---------------------|-------|------|------|------|
| Synthetic vitreous fibres                      |      |                      |       |     |     |                     |       |      |      |      |
| Continuous filament glass fibres               |      |                      |       |     |     |                     |       |      |      |      |
| Respirable                                     | –    | 1f/cc <sup>(h)</sup> | –     | –   |     |                     |       |      |      |      |
| Inhalable                                      | –    | 5mg/m <sup>3</sup>   |       |     |     |                     |       |      |      |      |
| Glass wool fibres                              | –    | 1f/cc <sup>(h)</sup> |       |     |     |                     |       |      |      |      |
| Rock wool fibres                               | –    | 1f/cc <sup>(h)</sup> |       |     |     |                     |       |      |      |      |
| Stag wool fibres                               | –    | 1f/cc <sup>(h)</sup> |       |     |     |                     |       |      |      |      |
| Special purpose glass fibres                   | –    | 1f/cc <sup>(h)</sup> |       |     |     |                     |       |      |      |      |
| Talc (containing no asbestos fibres)           | –    | 2                    | –     | –   | –   | 1                   | –     | –    |      |      |
|                                                |      | (respirable dust)    |       |     |     | (respirable dust)   |       |      |      |      |
| Talc (containing asbestos fibres)              |      |                      |       |     |     |                     |       |      |      |      |
|                                                |      | Use asbestos         |       |     |     |                     |       |      |      |      |
|                                                |      | TLV-TWA              |       |     |     |                     |       |      |      |      |
| Tantalum metal and oxide dusts                 | –    | 5                    | –     | –   | –   | 5                   | –     | 10   |      |      |
| TEDP, see Sulfotep                             |      |                      |       |     |     |                     |       |      |      |      |
| Tellurium and compounds, as Te                 | –    | 0.1                  | –     | –   | –   | 0.1 (except         | –     | –    |      |      |
|                                                |      |                      |       |     |     | hydrogen telluride) |       |      |      |      |
| Tellurium hexafluoride as Te                   | 0.02 | 0.10                 | –     | –   | –   | –                   | –     | –    |      |      |
| Temephos                                       | –    | 10                   | –     | –   | –   | –                   | –     | –    |      |      |
| TEPP                                           | SK   | 0.004                | 0.047 | –   | –   | SK                  | 0.004 | 0.05 | 0.01 | 0.12 |
| Terephthalic acid                              | –    | 10                   |       |     |     |                     |       |      |      |      |
| Terphenyls                                     | –    | –                    | –     | C5  | –   | –                   | –     | 0.5  | 5    |      |
| 1,1,1,2-Tetrabromoethane                       | –    | –                    | –     | –   | SK  | 0.5                 | 7     | –    | –    |      |
| 1,1,1,2-Tetrachloro-2,2-difluoroethane         | 500  | 4170                 | –     | –   |     | 100                 | 847   | 100  | 847  |      |
| 1,1,2,2-Tetrachloro-1,2-difluoroethane         | 500  | 4170                 | –     | –   |     | 100                 | 847   | 100  | 847  |      |
| 1,1,2,2-Tetrachloroethane                      | SK   | 1                    | 6.9   | –   | –   | –                   | –     | –    | –    | 1.5  |
| Tetrachloroethylene, see Perchloroethylene     |      |                      |       |     |     |                     |       |      |      |      |
| Tetrachloromethane, see Carbon tetrachloride   |      |                      |       |     |     |                     |       |      |      |      |
| Tetrachloronaphthalene                         | SK   | –                    | 2     | –   | –   | –                   | 2     | –    | 4    |      |
| Tetraethyl lead as Pb                          | SK   | –                    | 0.1   | –   | –   | SEE NOTE (K)        |       |      |      |      |
| Tetraethyl orthosilicate, see Ethyl silicate   |      |                      |       |     |     |                     |       |      |      |      |
| Tetrafluoroethylene                            |      | 2                    | –     | –   | –   |                     |       |      |      |      |
| Tetrahydrofuran                                |      | 200                  | 590   | 250 | 737 | 100                 | 300   | 200  | 599  | 2.0  |
| Tetramethyl lead as Pb                         | SK   | –                    | 0.15  | –   | –   | SEE NOTE (K)        |       |      |      |      |
| Tetramethyl orthosilicate, see Methyl silicate |      |                      |       |     |     |                     |       |      |      |      |
| Tetramethyl succinonitrile                     | SK   | 0.5                  | 2.8   | –   | –   | SK                  | 0.5   | 2.8  | 2    | 11   |
| Tetranitromethane                              |      | 0.005                | –     | –   | –   | –                   | –     | –    | –    | –    |
| Tetrasodium pyrophosphate anhydride            | –    | 5                    | –     | –   |     |                     |       |      |      |      |
| decahydrate                                    | –    | 5                    | –     | –   |     |                     |       |      |      |      |

Table 5.12 Cont'd

| Substance                                                     |    | Threshold limit values (USA) |                                     |                           |                                     | Occupational exposure limits (UK) |                           |                           |                      | Air odour threshold (ppm; v/v) |
|---------------------------------------------------------------|----|------------------------------|-------------------------------------|---------------------------|-------------------------------------|-----------------------------------|---------------------------|---------------------------|----------------------|--------------------------------|
|                                                               |    | TWA (ppm) <sup>(a)</sup>     | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL (ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> | TWA <sup>(c)</sup> (ppm)          | (mg/m <sup>3</sup> )      | STEL <sup>(c)</sup> (ppm) | (mg/m <sup>3</sup> ) |                                |
| Tetryl                                                        |    | –                            | 2                                   | –                         | –                                   | SK                                | –                         | 1.5                       | –                    | 3                              |
| Thallium, soluble compounds, as Tl                            | SK | –                            | 0.1                                 | –                         | –                                   | SK                                | –                         | 0.1                       | –                    | –                              |
| 4,4'-Thiobis(6-tert-butyl- <i>m</i> -cresol)                  |    | –                            | 10                                  | –                         | –                                   | –                                 | 10                        | –                         | –                    | –                              |
| Thioglycolic acid                                             | SK | 1                            | 3.8                                 | –                         | –                                   | 1                                 | 3.8                       | –                         | –                    | –                              |
| Thionyl chloride                                              |    | –                            | –                                   | C1                        | C4.9                                | –                                 | –                         | 1                         | –                    | 5                              |
| Thiram                                                        |    | –                            | 1                                   | –                         | –                                   | –                                 | 5                         | –                         | –                    | 10                             |
| Tin                                                           |    |                              |                                     |                           |                                     |                                   |                           |                           |                      |                                |
| Metal                                                         |    | –                            | 2                                   | –                         | –                                   | –                                 | –                         | –                         | –                    | –                              |
| Oxide and inorganic compounds except SnH <sub>4</sub> , as Sn |    | –                            | 2                                   | –                         | –                                   | –                                 | 2                         | –                         | –                    | 4                              |
| Organic compounds as Sn                                       | SK | –                            | 0.1                                 | –                         | 0.2                                 | SK                                | –                         | 0.1                       | –                    | 0.2                            |
|                                                               |    |                              |                                     |                           |                                     |                                   | (except Cyhexin)          |                           |                      |                                |
|                                                               |    |                              |                                     |                           |                                     |                                   | 10 (total inhalable dust) |                           |                      |                                |
| Titanium dioxide                                              |    | –                            | 10 <sup>(i)</sup>                   | –                         | –                                   |                                   | 4 (respirable dust)       | –                         | –                    | –                              |
| Toluene                                                       |    | 50                           | 191                                 | 150                       | 565                                 | SK                                | 50                        | 191                       | 150                  | 574                            |
| Toluene-2,4-diisocyanate (TDI)                                |    | 0.005                        | 0.036                               | 0.02                      | 0.14                                | see Isocyanates                   |                           |                           |                      | 2.9                            |
| <i>p</i> -Toluenesulphonyl chloride                           |    | –                            | –                                   | –                         | –                                   | –                                 | –                         | –                         | –                    | 5                              |
| <i>o</i> -Toluidine                                           | SK | 2 <sup>(e)</sup>             | 8.8 <sup>(e)</sup>                  | –                         | –                                   | 0.2                               | 0.9                       | –                         | –                    | 0.17                           |
| <i>m</i> -Toluidine                                           | SK | 2                            | 8.8                                 | –                         | –                                   | –                                 | –                         | –                         | –                    | 0.25                           |
| <i>p</i> -Toluidine                                           | SK | 2 <sup>(e)</sup>             | 8.8 <sup>(e)</sup>                  | –                         | –                                   | –                                 | –                         | –                         | –                    | –                              |
| Toluol, see Toluene                                           |    |                              |                                     |                           |                                     |                                   |                           |                           |                      |                                |
| Toxaphene, see Chlorinated camphene                           |    |                              |                                     |                           |                                     |                                   |                           |                           |                      |                                |
| Tributyl phosphate                                            |    | 0.2                          | 2.2                                 | –                         | –                                   | –                                 | 5                         | –                         | –                    | 5                              |
| Trichloroacetic acid                                          |    | 1                            | 6.7                                 | –                         | –                                   | –                                 | –                         | –                         | –                    | –                              |
| 1,2,4-Trichlorobenzene                                        |    | –                            | –                                   | C5                        | C37                                 | 1                                 | 7.6                       | –                         | –                    | 1.4                            |
| 1,1,1-Trichlorobis (chlorophenyl)ethane                       |    | –                            | –                                   | –                         | –                                   | –                                 | 1                         | –                         | –                    | 3                              |
| 1,1,1-Trichloroethane, see Methyl chloroform                  |    |                              |                                     |                           |                                     |                                   |                           |                           |                      |                                |
| 1,1,2-Trichloroethane                                         | SK | 10                           | 55                                  | –                         | –                                   | –                                 | –                         | –                         | –                    | –                              |
| Trichloroethylene                                             |    | 50                           | 269                                 | 100                       | 535                                 | SK                                | 100                       | 550 MEL                   | 150                  | 820 MEL                        |
| Trichlorofluoromethane                                        |    | –                            | –                                   | C1000                     | C5710                               | 1000                              | 5710                      | 1250                      | 7140                 | 28                             |
| Trichloromethane, see Chloroform                              |    |                              |                                     |                           |                                     |                                   |                           |                           |                      | 5                              |
| Trichloronaphthalene                                          | SK | –                            | 5                                   | –                         | –                                   | –                                 | –                         | –                         | –                    | –                              |
| Trichloronitromethane, see Chloropicrin                       |    |                              |                                     |                           |                                     |                                   |                           |                           |                      |                                |
| 1,2,3-Trichloropropane                                        | SK | 10                           | 60                                  | –                         | –                                   | 50                                | 306                       | 75                        | 460                  | –                              |
| 1,1,2-Trichloro-1,2,2-trifluoroethane                         |    | 1000                         | 7670                                | 1250                      | 9590                                | 1000                              | 7790                      | 1250                      | 9740                 | 45                             |

|                                                                               |                    |                    |     |                    |                  |       |                                            |     |         |
|-------------------------------------------------------------------------------|--------------------|--------------------|-----|--------------------|------------------|-------|--------------------------------------------|-----|---------|
| Tricyclohexyltin hydroxide,<br>see Cyhexatin                                  |                    |                    |     |                    |                  |       |                                            |     |         |
| Tridymite, see Silica, crystalline                                            |                    |                    |     |                    |                  |       |                                            |     |         |
| Triethanolamine                                                               |                    | 5                  |     |                    |                  |       |                                            |     |         |
| Triethylamine                                                                 | 1                  | 3                  | 15  | 62                 | 10               | 42    | 15                                         | 63  | 0.48    |
| Trifluorobromomethane, see<br>Bromotrifluoromethane                           |                    |                    |     |                    |                  |       |                                            |     |         |
| 1,3,5-Triglycidyl-s-triazinetriene                                            | –                  | 0.05               | –   | –                  |                  |       |                                            |     |         |
| Triglycidyl iso-cyanurate                                                     | –                  | –                  | –   | –                  | –                | 0.1   | –                                          | –   |         |
| Trimellitic anhydride, see Benzene-<br>1,2,4-tricarboxylic acid 1,2-anhydride |                    |                    |     |                    |                  |       |                                            |     |         |
| Trimethylamine                                                                | 5                  | 12                 | 15  | 36                 | 10               | 25    | 15                                         | 37  | 0.00044 |
| Trimethyl benzene                                                             | 25                 | 123                | –   | –                  | 25               | 125   | –                                          | –   | 0.55    |
| 3,5,5-Trimethylcyclohex-2-enone                                               | –                  | –                  | –   | –                  | –                | –     | 5                                          | 29  |         |
| Trimethyl phosphite                                                           | 2                  | 10                 | –   | –                  | 2                | 10    | –                                          | –   | 0.00010 |
| 2,4,6-Trinitrophenol, see Picric acid                                         |                    |                    |     |                    |                  |       |                                            |     |         |
| 2,4,6-Trinitrophenylmethylnitramine,<br>see Tetryl                            |                    |                    |     |                    |                  |       |                                            |     |         |
| 2,4,6-Trinitrotoluene (TNT)                                                   | SK                 | –                  | 0.1 | –                  | –                | –     | 0.5                                        | –   | –       |
| Triorthocresyl phosphate                                                      | SK                 | –                  | 0.1 | –                  | –                | –     | 0.1                                        | –   | 0.3     |
| Triphenyl amine                                                               | –                  | 5                  | –   | –                  | –                | –     | –                                          | –   | –       |
| Triphenyl phosphate                                                           | –                  | 3                  | –   | –                  | –                | 3     | –                                          | 6   |         |
| Tripoli, see Silica, crystalline                                              |                    |                    |     |                    |                  |       |                                            |     |         |
| Tungsten as W                                                                 |                    |                    |     |                    |                  |       |                                            |     |         |
| Insoluble compounds                                                           | –                  | 5                  | –   | 10                 | –                | 5     | –                                          | 10  |         |
| Soluble compounds                                                             | –                  | 1                  | –   | 3                  | –                | 1     | –                                          | 3   |         |
| Turpentine                                                                    | 100                | 566                | –   | –                  | 100              | 566   | 150                                        | 850 |         |
| Uranium (natural)                                                             |                    |                    |     |                    |                  |       |                                            |     |         |
| Soluble and insoluble compounds<br>as U                                       | –                  | 0.2 <sup>(g)</sup> | –   | 0.6 <sup>(g)</sup> | –                | 0.2   | –                                          | 0.6 |         |
| <i>n</i> -Valeraldehyde                                                       | 50                 | 176                | –   | –                  | –                | –     | –                                          | –   | 0.028   |
| Vanadium pentoxide as V <sub>2</sub> O <sub>5</sub>                           |                    |                    |     |                    |                  |       |                                            |     |         |
| Respirable dust and fume                                                      | –                  | 0.05               | –   | –                  | }                |       | 0.5 (total<br>inhalable dust)              | –   | –       |
|                                                                               |                    |                    |     |                    |                  |       | 0.04 (Fume<br>and respirable<br>dust) as V | –   | –       |
| Vegetable oil mists                                                           | –                  | 10                 | –   | –                  | –                | –     | –                                          | –   |         |
| Vinyl acetate                                                                 | 10                 | 35                 | 15  | 52                 | 10               | 36    | 20                                         | 72  | 0.50    |
| Vinyl benzene, see Styrene                                                    |                    |                    |     |                    |                  |       |                                            |     |         |
| Vinyl bromide                                                                 | 0.5 <sup>(e)</sup> | 2.2 <sup>(e)</sup> | –   | –                  | 5                | 20    | –                                          | –   |         |
| Vinyl chloride                                                                | 1 <sup>(g)</sup>   | 2.6 <sup>(g)</sup> | –   | –                  | 7 <sup>(l)</sup> | – MEL | –                                          | –   | 3000    |
| Vinyl cyanide, see Acrylonitrile                                              |                    |                    |     |                    |                  |       |                                            |     |         |
| Vinyl cyclohexene dioxide                                                     | SK                 | 0.1                | 0.6 | –                  | –                | –     | –                                          | –   |         |
| Vinyl fluoride                                                                | 1 <sup>(e)</sup>   | –                  | –   | –                  |                  |       |                                            |     |         |

Table 5.12 Cont'd

| Substance                                        |    | Threshold limit values (USA) |                                     |                              |                                     |     | Occupational exposure limits (UK) |                      |                              |                      | Air odour<br>threshold<br>(ppm; v/v) |
|--------------------------------------------------|----|------------------------------|-------------------------------------|------------------------------|-------------------------------------|-----|-----------------------------------|----------------------|------------------------------|----------------------|--------------------------------------|
|                                                  |    | TWA<br>(ppm) <sup>(a)</sup>  | (mg/m <sup>3</sup> ) <sup>(b)</sup> | STEL<br>(ppm) <sup>(a)</sup> | (mg/m <sup>3</sup> ) <sup>(b)</sup> |     | TWA <sup>(c)</sup><br>(ppm)       | (mg/m <sup>3</sup> ) | STEL <sup>(c)</sup><br>(ppm) | (mg/m <sup>3</sup> ) |                                      |
| Vinylidene chloride                              |    | 5                            | 20                                  | 20                           | 79                                  |     | 10                                | 40 MEL               | –                            | –                    | 190                                  |
| Vinylidene fluoride                              |    | 500                          | –                                   | –                            | –                                   |     |                                   |                      |                              |                      |                                      |
| Vinyl toluene                                    |    | 50                           | 242                                 | 100                          | 483                                 |     | –                                 | –                    | –                            | –                    | 10                                   |
| VM & P naphtha                                   |    | 300                          | 1370                                | –                            | –                                   |     | –                                 | –                    | –                            | –                    |                                      |
| Warfarin                                         |    | –                            | 0.1                                 | –                            | –                                   |     | –                                 | 0.1                  | –                            | –                    | 0.3                                  |
| Welding fumes (NOC)                              |    | –                            | 5 <sup>(i)</sup>                    | –                            | –                                   |     | –                                 | 5                    | –                            | –                    |                                      |
| White spirit                                     |    | –                            | –                                   | –                            | –                                   |     | see EH 40 for calculation         |                      |                              |                      |                                      |
| Wood dust (certain hardwoods e.g.<br>beech, oak) |    | –                            | 1 <sup>(g)</sup>                    | –                            | –                                   | SEN | –                                 | 5 MEL                | –                            | –                    |                                      |
| Softwood                                         |    | –                            | 5                                   | –                            | 10                                  |     | –                                 | 5 MEL                | –                            | –                    |                                      |
| Wool process dust                                |    | –                            | –                                   | –                            | –                                   |     | –                                 | 10                   | –                            | –                    |                                      |
| Xylene                                           |    |                              |                                     |                              |                                     |     |                                   |                      |                              |                      |                                      |
| o-,m-,p-isomers                                  |    | 100                          | 434                                 | 150                          | 651                                 | SK  | 100                               | 441                  | 150                          | 662                  | 1.1 (meta)                           |
| m-Xylene α, α'-diamine                           | SK | –                            | –                                   | –                            | CO.1                                |     | –                                 | –                    | –                            | –                    |                                      |
| Xylidine, mixed isomers                          | SK | 0.5 <sup>(e)</sup>           | 2.5 <sup>(e)</sup>                  | –                            | –                                   | SK  | 2                                 | 10                   | 10                           | 50                   | 0.056<br>(2,4-Xylidine)              |
| Yttrium, metal and compounds, as Y               |    |                              | –                                   | –                            | –                                   |     | –                                 | 1                    | –                            | –                    | 3                                    |
| Zinc chloride fume                               |    | –                            | 1                                   | –                            | 2                                   |     | –                                 | 1                    | –                            | –                    | 2                                    |
| Zinc chromates as Cr                             |    | –                            | 0.01 <sup>(g)</sup>                 | –                            | –                                   |     | –                                 | –                    | –                            | –                    |                                      |
| Zinc distearate                                  |    |                              |                                     |                              |                                     |     |                                   |                      |                              |                      |                                      |
| Total inhalable dust                             |    | –                            | –                                   | –                            | –                                   |     | –                                 | 10                   | –                            | –                    | 20                                   |
| Respirable dust                                  |    | –                            | –                                   | –                            | –                                   |     | –                                 | 4                    | –                            | –                    |                                      |
| Zinc oxide                                       |    |                              |                                     |                              |                                     |     |                                   |                      |                              |                      |                                      |
| Fume                                             |    | –                            | 5                                   | –                            | 10                                  |     | –                                 | 5                    | –                            | –                    | 10                                   |
| Dust                                             |    | –                            | 10                                  | –                            | –                                   |     | –                                 | –                    | –                            | –                    |                                      |
| Zirconium and compounds, as Zr                   |    | –                            | 5                                   | –                            | 10                                  |     | –                                 | 5                    | –                            | –                    | 10                                   |

C Ceiling limit

MEL Maximum exposure limit

NOC Not otherwise classified

SEN Capable of causing respiratory sensitization; skin sensitizers have not been given a separate notation

SK Can be absorbed through skin

This table is a useful guide but because standards are continually under review and many caveats apply reference should be made to the most recent edition of HSE EH 40 and the AGGIH TLV list for current values and their interpretation. Often carcinogens are not assigned a hygiene standard.

<sup>(a)</sup> Parts of vapour or gas per million parts of contaminated air by volume at 25 °C and 760 torr (1.013 bar).

<sup>(b)</sup> Milligrams of substance per m<sup>3</sup> air.

<sup>(c)</sup> Value shown is OES unless otherwise indicated as MEL.

(d) Simple asphyxiant. Some gases and vapours present at high concentrations act as asphyxiants by reducing the oxygen content of air. Many of these are odourless and colourless. Many also pose a fire or explosion risk, often at values below which asphyxiation can occur. (Although capable of asphyxiation, they are not considered to be substances hazardous to health under COSHH.)

(e) Suspected human carcinogens – see TLV Appendix A, Category A2 (below).

(f) The value is for total dust containing no asbestos and <1% crystalline silica.

(g) Confirmed human carcinogen – see TLV Appendix, A, Category A1 (below).

(h) Fibres longer than 5 µm and with an aspect ratio ≥3:1 as determined by the membrane filter method at 400–450X magnification (4 mm objective) phase contrast illumination.

(i) Welding fumes cannot be classified simply. The composition and quantity of both are dependent on the alloy being welded and the process and electrodes used. Reliable analysis of fumes cannot be made without considering the nature of the welding process and system being examined; reactive metals and alloys such as aluminium and titanium are arc-welded in a protective inert atmosphere such as argon. These arcs create relatively little fume, but they do create an intense radiation which can produce ozone. Similar processes are used to arc-weld steels, also creating a relatively low level of fumes. Ferrous alloys also are arc-welded in oxidizing environments that generate considerable fume and can produce carbon monoxide instead of ozone. Such fumes generally are composed of discrete particles of amorphous slags containing iron, manganese, silicon, and other metallic constituents depending on the alloy system involved. Chromium and nickel compounds are found in fumes when stainless steels are arc-welded. Some coated and flux-cored electrodes are formulated with fluorides and the fumes associated with them can contain significantly more fluorides than oxides. Because of the above factors, arc-welding fumes frequently must be tested for individual constituents that are likely to be present to determine whether specific TLVs are exceeded. Conclusions based on total fume concentration are generally adequate if no toxic elements are present in welding rod, metal, or metal coating and conditions are not conducive to the formation of toxic gases.

Most welding, even with primitive ventilation, does not produce exposures inside the welding helmet above 5 mg/m<sup>3</sup>. That which does, should be controlled.

(j) UK control limits for asbestos:

|                             |                                                                 |
|-----------------------------|-----------------------------------------------------------------|
| Chrysotile                  | 0.3 fibres/ml of air averaged over any continuous 4 hr period   |
|                             | 0.9 fibres/ml of air averaged over any continuous 10 min period |
| Any other form of asbestos, | 0.2 fibres/ml of air averaged over any continuous 4 hr period   |
| alone or in mixtures        | 0.6 fibres/ml of air averaged over any continuous 10 min period |

Action levels for cumulative exposures within a 12 week period:

(a) for chrysotile, 72 fibre hours/ml of air

(b) for any other form of asbestos, alone or in mixtures, 48 fibre hours/ml of air

(c) for both types of exposure at different times within the period, a proportionate number of fibre hours/ml

The lack of limits should not be taken to imply an absence of hazard. In the absence of a specific OEL for a particular dust, exposure should be adequately controlled and where there is no indication of the need for a lower value, personal exposure should be kept below both 10 mg/m<sup>3</sup> 8 hr TWA total inhalable dust and 4 mg/m<sup>3</sup> 8 hr TWA respirable dust.

(k) UK limits for lead are 8 hr TWA concentrations as follows:

|                             |   |                               |
|-----------------------------|---|-------------------------------|
| Lead other than lead alkyls | – | 0.15 mg/m <sup>3</sup> of air |
| Lead alkyls                 | – | 0.1 mg/m <sup>3</sup> of air  |

These are ceiling values that must not be exceeded when calculating 8 hr TWA. They should be read in conjunction with biological limits for lead.

(l) As measured by the vertical elutriator cotton-dust samples.

(m) Polytetrafluoroethylene decomposition products: thermal decomposition of the fluorocarbon chain in air leads to the formation of oxidized products containing carbon, fluorine and oxygen. Because these products decompose in part by hydrolysis in alkaline solution, they can be quantitatively determined in air as fluoride to provide an index of exposure. No TLV is recommended pending determination of the toxicity of the products, but air concentration should be minimal. (Trade names: Algoflon, Fluon, Teflon, Tetran.)

(n) In the UK vinyl chloride is also subject to an overriding annual maximum exposure limit of 3 ppm.

(o) As sampled by a method that does not collect vapour.

#### **TLV Appendix A: Carcinogens** (excerpts)

The Chemical Substances Threshold Limit Values Committee classifies certain substances found in the occupational environment as either confirmed or suspected human

**Table 5.12 Cont'd**

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carcinogens. The present listing of substances that have been identified as carcinogens takes two forms: those for which a TLV has been assigned and those for which environmental and exposure conditions have not been sufficiently defined to assign a TLV. Where a TLV has been assigned, it does not necessarily imply the existence of a biological threshold; however, if exposures are controlled to this level, we would not expect to see a measurable increase in cancer incidence or mortality.

Two categories of carcinogens are designated:

A1 – *Confirmed Human Carcinogens*. Substances, or substances associated with industrial process, recognized to have carcinogenic potential.

A2 – *Suspected human carcinogens*. Chemical substances, or substances associated with industrial process, which are suspect of inducing cancer, based on their limited epidemiological evidence or demonstration of carcinogenesis in one or more animal species by appropriate methods.

Exposures to carcinogens must be kept to a minimum. Workers exposed to A1 carcinogens without a TLV should be properly equipped to eliminate to the fullest extent possible all exposure to the carcinogen. For A1 carcinogens with a TLV and for A2 carcinogens, worker exposure by all routes should be carefully controlled to levels *as low as reasonably achievable* (ALARA) below the TLV.



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# Flammable chemicals

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Certain chemicals pose fire and explosion risks because:

They ignite easily. Vapours often travel a considerable distance to an ignition source remote from the point of chemical escape.

Considerable heat is generated. Many volatile substances liberate heat at a rate some ten times faster than burning wood.

The fire spreads easily by, e.g., running liquid fire, a pool fire, a fire ball, heat radiation or thermal lift (convection).

Explosion: a confined vapour cloud explosion (CVCE) can result from ignition of vapour within a building or equipment; a boiling liquid expanding vapour explosion (BLEVE) can result when unvented containers of flammable chemicals burst with explosive violence as a result of the build-up of internal pressure; unconfined vapour cloud explosion (UVCE) can result from ignition of a very large vapour or gas/air cloud.

Clearly, flammable chemicals also pose a health risk if the substance or its thermal degradation or combustion products are toxic, (e.g. carbon monoxide) or result in oxygen deficiency because oxygen is consumed. Hot smoke and other respiratory irritants, e.g. aldehydes, are also produced.

## Ignition and propagation of a flame front

Normally flame propagation requires

- (a) fuel, gas or vapour (or combustible dust) within certain concentration limits,
- (b) oxygen supply (generally from air) above a certain minimum concentration, *and*
- (c) ignition source of minimum temperature, energy and duration.

All three, represented by the three corners of a triangle (Figure 6.1), must generally be present. But no ignition source is needed if a material is above a specific temperature (see p. 214), and no additional oxygen is required if an oxidizing agent is present or in a few cases when oxygen is within the fuel molecule (e.g. ethylene oxide).

### ***Fuel***

Liquids and solids do not burn as such, but on exposure to heat vaporize or undergo thermal degradation to liberate flammable gases and vapours which burn. Some chemicals undergo spontaneous combustion (see page 214).

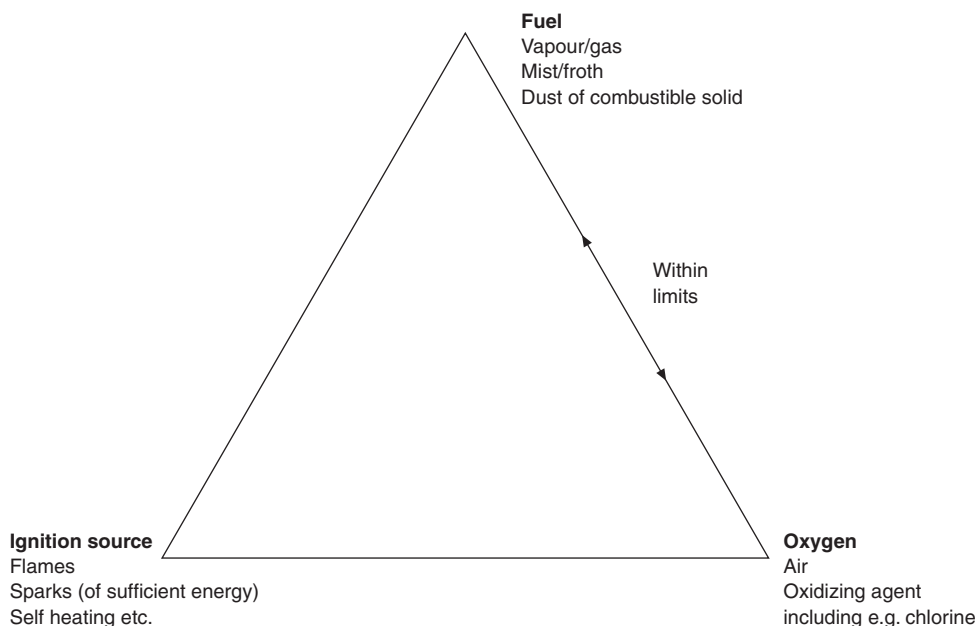


**Figure 6.1** *Fire triangle*

### *Flammable limits*

Flammable gases and volatile liquids are particularly hazardous because of the relative ease with which they produce mixtures with air within the flammable range. An increase in the surface area of any liquid facilitates vaporization. For each substance there is a minimum concentration of gas or vapour below which flame propagation will not occur (i.e. the mixture is too lean). There is also a concentration above which the mixture is too rich to ignite. The limits of flammability are influenced by temperature and pressure (e.g. the flammable range expands with increased temperature). Generally, the wider the flammable range the greater the fire risk. Flammability limits for a range of chemicals are summarized in Table 6.1.

The vapour pressure of a flammable substance also provides an indication of how easily the material will volatilize to produce flammable vapours; the higher the vapour pressure, the greater the risk. Lists of vapour pressures usually contain data obtained under differing conditions but inspection of boiling points (when the vapour pressure equals atmospheric pressure) gives a first approximation of the ease with which substances volatilize. Table 6.1 therefore includes both boiling point and vapour pressure data.

### *Flash point*

The flash point represents the minimum temperature at which an ignitable mixture exists above a liquid surface. By definition, flash points are inapplicable to gases. Some solids, e.g. naphthalene and camphor, are easily volatilized on heating so that flammable mixtures develop above the solid surface and hence flash points can be determined. (However, although these substances can be ignited, they generally need to be heated above their flash points in order for combustion to be sustained: this is the 'fire point'.)

Flash point determinations may be made in 'closed' or 'open' containers, giving different values;

these are non-equilibrium methods. Alternatively equilibrium methods are available. Typical flash points are quoted in Table 6.1 and, unless otherwise stated, these relate to closed cup measurements. In general, the lower the flash point the greater the potential for fire: materials with flash points at or below ambient temperature are highly flammable and can inflame at ambient temperature on contact with ignition sources. Flash point is used to classify liquids under many legislative systems: in the UK liquids with flash points  $<32^{\circ}\text{C}$  (and which, when heated under specific test conditions and exposed to an external source of flame applied in a standard manner, supports combustion) are defined as ‘highly flammable’ under the Highly Flammable Liquid and Liquefied Petroleum Gas Regulations.

Chemicals may ignite below their flash points if the substance:

Is in the form of a mist (or froth).

Covers a large surface area (e.g. when absorbed on porous media).

Contains a small amount of a more volatile flammable liquid, e.g. due to deliberate or accidental contamination.

In addition

Flash points are reduced by increases in ambient pressure. Thus the flash point of toluene at sea level (101.3 kPa) is  $4.5^{\circ}\text{C}$  whereas at 83.3 kPa, e.g. in the mountains at 1685 m, the value is  $1^{\circ}\text{C}$ .

Materials with high flash points such as heavy oils and resins can produce flammable vapours due to thermal degradation on heating. Dangers therefore arise when welding, flame cutting empty drums/vessels once used to contain such materials due to the presence of residues.

Substances may be heated to their flash points by other substances with lower flash points burning in close proximity. Storage of flammable chemicals, therefore, needs careful consideration.

### *Vapour density*

The density of a vapour or gas at constant pressure is proportional to its relative molecular mass and inversely proportional to temperature. Since most gases and vapours have relative molecular masses greater than air (exceptions include hydrogen, methane and ammonia), the vapours slump and spread or accumulate at low levels. The greater the vapour density, the greater the tendency for this to occur. Gases or vapours which are less dense than air can, however, spread at low level when cold (e.g. release of ammonia refrigerant). Table 6.1 includes vapour density values.

### ***Dust explosions***

Increasing the surface area of a combustible solid enhances the ease of ignition. Hence dust burns more rapidly than the corresponding bulk solid; combustion of dust layers can result in rapid flame spread by ‘train firing’. Solid particles less than about  $10\text{ }\mu\text{m}$  in diameter settle slowly in air and comprise ‘float dust’ (see p. 51 for settling velocities). Such particles behave, in some ways, similarly to gas and, if the solid is combustible, a flammable dust–air mixture can form within certain limits. Larger particles also take part, since there is a distribution of particle sizes, and ignition can result in a dust explosion.

Dust explosions are relatively rare but can involve an enormous energy release. A *primary* explosion, involving a limited quantity of material, can distribute accumulations of dust in the atmosphere which, on ignition, produces a severe *secondary* explosion.

Small particles are required, to provide a large surface-area-to-mass ratio and for the solid to remain in suspension. Surface absorption of air (oxygen) by the solid, or the evolution of combustible gas or vapour on heating, may be a predisposing factor. The presence of moisture reduces the tendency to ignite: it also favours agglomeration to produce larger particles. An increase in the proportion of inert solid in particles tends to reduce combustibility.

The explosive range of dusts in air can be very wide. The limits vary with the chemical composition and with the size of the particles. The lower limits are equivalent to a dense fog in appearance. The upper limits are ill defined but are not generally of practical significance. The important characteristics are the ease of ignition, lower explosive limits, the maximum explosion pressure and the rates of pressure rise. Organic or carbonaceous materials, or easily oxidizable metals (e.g. aluminium or magnesium) are more hazardous than nitrogenous organic materials. The least hazardous materials are those which contain an appreciable amount of mineral matter.

For a summary of data for a range of dusts refer to Table 6.2.

### ***Oxygen requirements***

Most substances require a supply of oxygen in order to burn. Air contains about 21% oxygen. Gases and vapours can produce flammable mixtures in air within certain limits. When the oxygen content of air is increased (e.g. by enrichment with pure oxygen from a leaking cylinder) the fire hazard is increased. Conversely, lowering the oxygen by, for instance, the presence of an inert gas such as nitrogen, argon, or carbon dioxide, reduces the fire risk. Some chemicals contain their own supply of oxygen (e.g. perchlorates) and can burn even in an oxygen-deficient atmosphere. Just as chemicals can react violently with oxygen to produce a fire, certain substances can inflame on reaction with other oxidizing agents (e.g. hydrocarbons with chlorine). Upper and lower flammable limits exist for such systems. Oxidizing agents generally assist combustion (see page 234).

There is a critical oxygen content below which ignition of combustible dusts or gases will not occur and this can provide a means for safe operation under an inert atmosphere, i.e. 'inerting'.

### ***Ignition sources***

Combustion is generally initiated by the introduction of a finite amount of energy to raise a finite volume of the material to its ignition temperature. Potential ignition sources for vapour-air mixtures are listed in Table 6.3, and temperatures in Table 6.4. Heat sources can be chemical energy (spontaneous combustion, chemical reaction), mechanical energy (e.g. friction), radiant energy, solar energy, static energy or electrical current. Thus heat is generated from electrical current by resistance, arcing or sparking. Resistance arises when the current flow exceeds the capacity of the wire. The result is often a blown fuse, tripped circuit breaker or heating of the circuit wire. Arcing occurs when electrical current jumps from one point to another, e.g. in a switch or connection box when wires separate from connections, or as a result of worn insulation between positive and neutral wires.

Common ignition sources include:

Naked flames (e.g. Bunsen burners, welding torches, blow lamps, furnaces, pilot lights, matches, glowing cigarettes or embers).

Sparks created by arcs in electrical switchgear, engines, motors, or by friction (e.g. lighter spark). Aluminium, magnesium, titanium and their alloys have an affinity for oxygen and in a thermite reaction with rust produce temperatures  $\leq 3000$  °C. A thermite flash can result from the

**Table 6.3 Sources of ignition****Mechanical sources**

|                |                                                                                                                                                                                                                                                                                                                                                                                                                   |
|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Friction       | <ul style="list-style-type: none"> <li>Metal to metal</li> <li>Metal to stone</li> <li>Rotary impact</li> <li>Abrasive wheel</li> <li>Buffing disc</li> <li>Tools, drill</li> <li>Boot studs</li> <li>Bearings</li> <li>Misaligned machine parts</li> <li>Broken machine parts</li> <li>Chocking or jamming of material</li> <li>Poor adjustment of power drives</li> <li>Poor adjustment of conveyors</li> </ul> |
| Missiles       | <ul style="list-style-type: none"> <li>Hot missiles</li> <li>Missile friction</li> </ul>                                                                                                                                                                                                                                                                                                                          |
| Metal fracture | <ul style="list-style-type: none"> <li>Cracking of metal</li> </ul>                                                                                                                                                                                                                                                                                                                                               |

**Electrical sources**

|                    |                                                                                                                                                                                                                                                                                       |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Electrical current | <ul style="list-style-type: none"> <li>Switch gear</li> <li>Cable break</li> <li>Vehicle starter</li> <li>Broken light</li> <li>Electric motor</li> </ul>                                                                                                                             |
| Electrostatic      | <ul style="list-style-type: none"> <li>Liquid velocity</li> <li>Surface charge</li> <li>Personal charge</li> <li>Rubbing of plastic or rubber</li> <li>Liquid spray generation</li> <li>Mist formation</li> <li>Water jetting</li> <li>Powder flow</li> <li>Water settling</li> </ul> |
| Lightning          | <ul style="list-style-type: none"> <li>Direct strike</li> <li>Hot spot</li> <li>Induced voltage</li> </ul>                                                                                                                                                                            |
| Stray currents     | <ul style="list-style-type: none"> <li>Railway lines</li> <li>Cable break</li> <li>Arc welding</li> </ul>                                                                                                                                                                             |
| Radio frequency    | <ul style="list-style-type: none"> <li>Aerial connection</li> <li>Intermittent contact</li> </ul>                                                                                                                                                                                     |

**Thermal sources**

|             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hot surface | <ul style="list-style-type: none"> <li>Hot spot</li> <li>Catalyst hot spots</li> <li>Incandescent particles from incinerators, flarestacks, chimneys</li> <li>Vehicle exhaust</li> <li>Steam pipes</li> <li>Refractory lining, hot slag</li> <li>Foreign metal in crushing and grinding equipment</li> <li>Electric heater</li> <li>Smoking</li> <li>Glowing embers, brands</li> <li>Drying equipment</li> <li>Molten metal or glass</li> <li>Heat transfer salt</li> <li>Hot oil/salt transfer lines</li> </ul> |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 6.3 Cont'd

|                                       |                                                                                                                                                                                                                                                               |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | Boiler ducts or flues<br>Electric lamps<br>Hot process equipment<br>Welding metal<br>Induction brazing<br>Hot plates<br>Soldering irons                                                                                                                       |
| Self-heating                          | Oxidation<br>Reaction<br>Activated carbon                                                                                                                                                                                                                     |
| Flames                                | Pilot light<br>Primary fire involving liquid (running or pool), solid or gas<br>Matches, cigarette lighters<br>Cutting, welding<br>Portable gas heaters<br>Stoves; natural gas, LPG, oil or solid fuel – fired<br>Burners<br>Arson<br>Blow torches<br>Brazing |
| Compression                           | Pressure change<br>Piston                                                                                                                                                                                                                                     |
| Engines                               | Exhaust<br>Engine overrun<br>Hydraulic spray into air intake                                                                                                                                                                                                  |
| Diffusion                             | High pressure change                                                                                                                                                                                                                                          |
| <b>Chemical sources</b>               |                                                                                                                                                                                                                                                               |
| Peroxides                             | Oxygen release<br>Unstable<br>Decomposition                                                                                                                                                                                                                   |
| Polymerization                        | Exothermic reaction<br>Catalyst<br>Lack of inhibitor<br>Crystallization                                                                                                                                                                                       |
| Spontaneous                           | Pyrophoric deposit<br>Deposits<br>Water reactive<br>Sulphides<br>Oily rags, oil impregnation of lagging<br>Heat transfer salt                                                                                                                                 |
| <b>Reaction with other substances</b> |                                                                                                                                                                                                                                                               |
| Thermite reaction                     | Rust<br>Exothermic reactions with aluminium, aluminium alloys                                                                                                                                                                                                 |
| Unstable substances                   | Acetylides                                                                                                                                                                                                                                                    |
| Decomposition                         | Initiator<br>Temperature<br>Catalyst                                                                                                                                                                                                                          |

striking of a smear or thin coating of alloy on rusty steel with a hammer. The glancing impact of stainless steel, mild steel, brass, copper–beryllium bronze, aluminium copper and zinc onto aluminium smears on rusty steel can initiate a thermite reaction of sufficient thermal energy to ignite flammable gas/vapour–air atmosphere or dust clouds.

**Table 6.4 Approximate temperatures of common ignition sources**

| <b>Flame/spark sources</b>        | <i>Ignition temperature (°C)</i> |
|-----------------------------------|----------------------------------|
| Candles                           | 640–940                          |
| Matches                           | 870                              |
| Manufactured gas flame            | 900–1340                         |
| Propane flame                     | 2000                             |
| Light bulb element                | 2483                             |
| Methane flame                     | 3042                             |
| Electrical short circuit or arc   | 3870                             |
| <b>Non-flame sources</b>          |                                  |
| Steam pipes at normal pressure    | 100                              |
| Steam pipes at 10 psi (0.7 bar)   | 115                              |
| Light bulb, normal                | 120                              |
| Steam pipes at 15 psi (1 bar)     | 121                              |
| Steam pipes at 30 psi (2 bar)     | 135                              |
| Steam pipes at 50 psi (3.5 bar)   | 148                              |
| Steam pipes at 75 psi (5 bar)     | 160                              |
| Steam pipes at 100 psi (7 bar)    | 170                              |
| Steam pipes at 150 psi (10.5 bar) | 185                              |
| Steam pipes at 200 psi (14 bar)   | 198                              |
| Steam pipes at 300 psi (21 bar)   | 217                              |
| Steam pipes at 500 psi (35 bar)   | 243                              |
| Steam pipes at 1000 psi (70 bar)  | 285                              |
| Cigarette, normal                 | 299                              |
| Soldering iron                    | 315–432                          |
| Cigarette, insulated              | 510                              |
| Light bulb, insulated             | 515                              |

Petroleum vapour is unlikely to be ignited by impact of steel on steel produced by hand. Power operation can however produce incendive sparks. Hydrogen and perhaps ethylene, acetylene or carbon disulphide can be ignited by the impact of steel on steel using hand tools. If non-sparking tools are used, care must be taken to avoid embedded grit particles since impact of steel on 'rock' poses a greater hazard. Impact on flint or grit can produce incendive sparks irrespective of striking material. Friction in bearings is a common ignition source. Radiant heat sources include furnaces, vats, cooking stoves and other hot surfaces. Solar heat from the direct rays of the sun may directly, or if magnified by, e.g., glass bottles or flasks, provide sufficient energy to raise the temperature of chemicals to their flash-point. Vehicular petrol engines are potential ignition sources by means of the spark-ignition system, dynamo or battery, or hot exhaust pipe. Non-flameproof diesel engines are potential ignition sources due to a hot exhaust pipe or carbonaceous particles or flames from the exhaust. Spark due to static electricity associated with the separation of two dissimilar materials (Table 6.5). The charges may be transported/conducted some distance after separation before there is sufficient accumulation to produce a spark, e.g. in the flow of liquids or powders. The size of the charge is generally small but the potential difference may be very high such that a spark is of sufficient energy for ignition.

Electrostatic charge generated by a liquid flow through a pipe depends on the electrical conductivity of the liquid. With a liquid of high electrical conductivity, the charge is easily generated but quickly dissipated. Hazardous liquids are generally those with conductivities in the range 0.1 to 1000 ps/m. The rate of charge generation increases with increase in flowrate and constrictions in the pipeline.

Friction resulting from two surfaces rubbing together, e.g. drive belts in contact with their

**Table 6.5 Operations which may result in static charge generation**

|               |                                                                                                                                                                                       |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Solid–solid   | Persons walking<br>Grit blasting<br>Conveying of powders<br>Belts and pulleys<br>Fluidized beds                                                                                       |
| Solid–liquid  | Flow of liquids in pipelines/filters<br>Settling of particles in liquid (e.g. rust and sludge)                                                                                        |
| Gas–liquid    | Released gas (air) bubbles rising in a large tank<br>Mist formation from LPG evaporation<br>Splash filling<br>Cleaning with wet steam<br>Mist formation from high pressure water jets |
| Liquid–liquid | Settling of water drops in oil                                                                                                                                                        |
| Solid–gas     | Mixing of immiscible liquids<br>Pneumatic conveying of solids<br>Fluidized beds                                                                                                       |

housing or guard, or metal surfaces rubbing against one another. Usually friction arises from poor maintenance (e.g. loose guard, inadequate lubrication).

Lightning. Protection is generally provided by earthing with low resistance, e.g.  $7\ \Omega$ , which should be short and direct. The recommended value for protection of plant is  $\leq 10\ \Omega$ .

A material that is above its autoignition temperature will ignite spontaneously on contact with air in the correct proportions (see Table 6.1 for minimum temperature of ignition source).

Ignition of a flammable dust–air mixture is more difficult than with flammable vapour–air mixtures. A larger source of heat is required, and a larger volume of fuel must be heated to the ignition point. The same range of potential ignition sources is applicable as for air–vapour mixtures.

At certain temperatures compounds will explode without application of a flame, as illustrated by the selection in Table 6.6.

### ***Spontaneous combustion***

Certain materials which are generally considered to be stable at ordinary temperatures can inflame even in the absence of normal ignition sources. Such spontaneous combustion results from exothermic autoxidation when the heat liberated exceeds that dissipated by the system. Materials prone to self-heating are listed in Table 6.7. In most cases, such fires involve relatively large, enclosed or thermally-insulated masses, and spontaneous combustion usually occurs after prolonged storage.

### ***Pyrophoric chemicals***

Pyrophoric chemicals are so reactive that on contact with air they undergo vigorous reaction with atmospheric oxygen (under ambient conditions or at elevated temperatures), or with water (Table 6.9). Examples include:

Certain metals/alloys – the alkali metals (lithium, potassium, sodium) and even some metals/alloys which undergo slow oxidation or are rendered passive in bulk form but which, in the finely divided state, inflame immediately when exposed to oxygen (e.g. aluminium, magnesium, zirconium).



**Table 6.6** Approximate temperatures at which selected substances will explode, without the application of a flame

| <b>Solids</b>                    | <i>Temperature</i> <sup>(1)</sup> (°C) |                    |
|----------------------------------|----------------------------------------|--------------------|
| Gun cotton (loose)               | 137                                    | 139 <sup>(2)</sup> |
| Cellulose dynamite               | 169                                    | 230                |
| Blasting gelatine (with camphor) | 174                                    |                    |
| Mercury fulminate                | 175                                    |                    |
| Gun cotton (compressed)          | 186                                    | 201                |
| Dynamite                         | 197                                    | 200                |
| Blasting gelatine                | 203                                    | 209                |
| Nitroglycerin                    | 257                                    |                    |
| Gunpowder                        | 270                                    | 300                |
| <b>Gases</b>                     |                                        |                    |
| Propylene                        | 497                                    | 511                |
| Acetylene                        | 500                                    | 515                |
| Propane                          | 545                                    | 548                |
| Hydrogen                         | 555                                    |                    |
| Ethylene                         | 577                                    | 599                |
| Ethane                           | 605                                    | 622                |
| Carbon monoxide                  | 636                                    | 814                |
| Manufactured gas                 | 647                                    | 649                |
| Methane                          | 656                                    | 678                |

<sup>(1)</sup> The value quoted is that at which the substance itself explodes, not the temperature at which its container ruptures with the possible subsequent ignition of the contents.

<sup>(2)</sup> The higher temperature is applicable when the heat rise is very rapid, i.e. if the rate of rise is slow then the explosion will occur at the lower temperature.

Phosphorus.

Certain phosphides, hydrides and silanes (e.g. hydrogen phosphide, silane).

Substances which react with water to liberate flammable gas, e.g. carbides (liberate acetylene), alkali metals (hydrogen), organometallics (hydrocarbons – see Table 6.8), and where the heat of reaction is sufficient to ignite the gas. Thus metals which are less electronegative than hydrogen (see Table 6.10) will displace this element from water or alcohols, albeit at different rates.

## **Explosions**

Fires sometimes initiate, or are followed by, explosions resulting in blast damage, missiles etc. These may trigger secondary events, e.g. fires, toxic releases or further explosions.

### *Types of explosion*

Confined vapour cloud explosion: gas or vapour burns in a confined volume and rapid expansion of the combustion products is restrained until failure of the container or building occurs.

Boiling liquid expanding vapour explosion: follows failure of a pressurized container of flammable liquid, e.g. LPG, or a sealed vessel containing volatile flammable liquids, under fire conditions. Ignition results in a fireball and missiles.

Dust explosion (refer to page 220).

Explosion due to thermal deflagration or detonation of a solid or liquid.

Unconfined vapour cloud explosion: a large flammable gas or vapour–air cloud burns in free space with sufficient rapidity to generate pressure waves, which propagate through the cloud and into the surrounding atmosphere. Such events are extremely rare.

**Table 6.7 Materials liable to self-heat****Liquid materials susceptible to self-heating when dispersed on a solid**

|                           |             |
|---------------------------|-------------|
| Bone oil                  | moderate    |
| Castor oil                | very slight |
| Coconut oil               | very slight |
| Cod liver oil             | high        |
| Corn oil                  | moderate    |
| Cotton seed oil (refined) | high        |
| Fish oil                  | high        |
| Lard                      | high        |
| Linseed oil (raw)         | very high   |
| Menhaden oil              | high        |
| Neatsfoot oil             | slight      |
| Oleic acid                | very slight |
| Oleo oil                  | very slight |
| Olive oil                 | slight      |
| Palm oil                  | moderate    |
| Peanut oil                | moderate    |
| Perilla oil               | high        |
| Pine oil                  | moderate    |
| Rape seed oil             | high        |
| Rosin oil                 | high        |
| Soya bean oil             | moderate    |
| Sperm oil                 | moderate    |
| Tallow                    | moderate    |
| Tallow oil                | moderate    |
| Tung oil                  | moderate    |
| Turpentine                | slight      |
| Whale oil                 | high        |

**Solid materials susceptible to self-heating in air**

|                           |                                     |
|---------------------------|-------------------------------------|
| Activated charcoal        | Jaggery soap                        |
| Animal feedstuffs         | Jute                                |
| Beans                     | Lagging contaminated with oils etc. |
| Bone meal, bone black     | Lamp-black                          |
| Brewing grains, spent     | Leather scrap                       |
| Carbon                    | Maize                               |
| Celluloid                 | Manure                              |
| Colophony powder material | Milk products                       |
| Copper powder             | Monomers for polymerization         |
| Copra                     | Palm kernels                        |
| Cork                      | Paper waste                         |
| Cotton                    | Peat                                |
| Cotton waste              | Plastic, powdered (various)         |
| Cottonseed                | Rags, impregnated                   |
| Distillers dried grain    | Rapeseed                            |
| Fats                      | Rice bran                           |
| Fertilizers               | Rubber scrap                        |
| Fishmeal                  | Sawdust                             |
| Flax                      | Seedcake                            |
| Foam and plastic          | Seeds                               |
| Grains                    | Silage                              |
| Grass                     | Sisal                               |
| Gum rosin                 | Soap powder                         |
| Hay                       | Soya beans                          |
| Hemp                      | Straw                               |
| Hides                     | Sulphur                             |
| Iron filings/wool/borings | Varnished fabric                    |
| Iron pyrites              | Wood chips                          |
| Ixtle                     | Wood fibreboard                     |

Table 6.7 Cont'd

|                                                                                                                                                     |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Wood flour                                                                                                                                          | Zinc powder |
| Wool waste                                                                                                                                          |             |
| <b>Fibrous materials are subject to self-heating when impregnated with the following vegetable/animal oils</b><br>(in decreasing order of tendency) |             |
| Cod liver oil                                                                                                                                       |             |
| Linseed oil                                                                                                                                         |             |
| Menhaden oil                                                                                                                                        |             |
| Perilla oil                                                                                                                                         |             |
| Corn oil                                                                                                                                            |             |
| Cottonseed oil                                                                                                                                      |             |
| Olive oil                                                                                                                                           |             |
| Pine oil                                                                                                                                            |             |
| Red oil                                                                                                                                             |             |
| Soya bean oil                                                                                                                                       |             |
| Tung oil                                                                                                                                            |             |
| Whale oil                                                                                                                                           |             |
| Castor oil                                                                                                                                          |             |
| Lard oil                                                                                                                                            |             |
| Black mustard oil                                                                                                                                   |             |
| Oleo oil                                                                                                                                            |             |
| Palm oil                                                                                                                                            |             |
| Peanut oil                                                                                                                                          |             |
| <b>Other materials subject to self-heating</b> (depending upon composition, method of drying, temperature, moisture content)                        |             |
| Desiccated leather                                                                                                                                  |             |
| Leather scraps                                                                                                                                      |             |
| Dried blood                                                                                                                                         |             |
| Household refuse                                                                                                                                    |             |
| Leather meal                                                                                                                                        |             |

NB This list is not exclusive

Table 6.8 Characteristics of some organometallic compounds in common use

|                                             |                                                                                                                                                                          |
|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Alkyl magnesium halides (Grignard reagents) | Usually prepared and handled in organic solvent<br>For alkyl groups of $\leq 4$ carbon atoms, the compounds react vigorously with water and the resulting alkane ignites |
| Butyl lithium                               | Pale yellow, caustic, extremely flammable liquid<br>May ignite if exposed to air<br>Reacts violently with water                                                          |
| Diethyl aluminium chloride                  | Colourless corrosive liquid<br>Ignites immediately upon contact with air<br>Reacts violently with water                                                                  |
| Diethyl zinc                                | Colourless malodorous liquids that are spontaneously flammable in air and react violently with water                                                                     |
| Dimethyl zinc                               |                                                                                                                                                                          |
| Dimethyl arsine                             | Colourless poisonous liquid<br>Ignites in air                                                                                                                            |
| Nickel carbonyl                             | Yellowish, volatile, toxic liquid, oxidizes in air and explodes at $\sim 60^\circ\text{C}$<br>Confirmed carcinogen                                                       |
| Sodium methylate                            | White powder, sensitive to air and decomposed by water                                                                                                                   |
| Triethyl aluminium                          | Colourless liquids which ignite in air and decompose explosively in cold water                                                                                           |
| Triethyl aluminium ethereate                |                                                                                                                                                                          |
| Trimethyl aluminium                         |                                                                                                                                                                          |

Table 6.9 Pyrophoric chemicals in common use

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Pyrophoric alkyl metals and derivatives</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Carbonylpotassium<br>Carbonylsodium<br>Dodecacarbonyldivanadium<br>Dodecacarbonyltetracobalt<br>Dodecacarbonyltriiron<br>Hexacarbonylchromium<br>Hexacarbonylmolybdenum<br>Hexacarbonyltungsten<br>Nonacarbonyldiiron<br>Octacarbonyldicobalt<br>Pentacarbonyliron<br>Tetracarbonylnickel                               | <b>Pyrophoric metal sulphides</b><br>(Ammonium sulphide)<br>Barium sulphide<br>Calcium sulphide<br>Chromium (II) sulphide<br>Copper (II) sulphide<br>Diantimony trisulphide<br>Dibismuth trisulphide<br>Dicaesium selenide<br>Dicerium trisulphide<br>Digold trisulphide<br>Europium (II) sulphide<br>Germanium (II) sulphide<br>Iron disulphide<br>Iron (II) sulphide<br>Manganese (II) sulphide<br>Mercury (II) sulphide<br>Molybdenum (IV) sulphide<br>Potassium sulphide<br>Rhenium (VII) sulphide<br>Silver sulphide<br>Sodium disulphide<br>Sodium polysulphide<br>Sodium sulphide<br>Tin (II) sulphide<br>Tin (IV) sulphide<br>Titanium (IV) sulphide<br>Uranium (IV) sulphide | Triethylarsine<br>Triethylborane<br>Triethylphosphine<br>Triisopropylphosphine<br>Trimethylarsine<br>Trimethylborane<br>Trimethylphosphine                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Compounds</b><br>Bis-dimethylstibinyl oxide<br>Bis(dimethylthallium) acetylide<br>Butyllithium<br>Diethylberyllium<br>Diethylcadmium<br>Diethylmagnesium<br>Diethylzinc<br>Diisopropylberyllium<br>Dimethylberyllium<br>Dimethylbismuth chloride<br>Dimethylcadmium<br>Dimethylmagnesium<br>Dimethylmercury<br>Dimethyl-phenylethynylthallium<br>Dimethyl- <i>i</i> -propynylthallium<br>Dimethylzinc<br>Ethoxydiethylaluminium<br>Methylbismuth oxide<br>Methylcopper<br>Methylthallium<br>Methylpotassium<br>Methylsilver<br>Methylsodium<br>Poly(methylenemagnesium)<br>Propylcopper<br>Tetramethyldistibine<br>Tetramethyllead<br>Tetramethylplatinum<br>Tetramethyltin<br>Tetravinyllead<br>Triethylantimony<br>Triethylbismuth<br>Triethylgallium<br>Trimethylantimony<br>Trimethylgallium<br>Trimethylthallium<br>Trivinylbismuth<br>Vinylthallium | <b>Pyrophoric metals</b><br>(in finely-divided state)<br>Caesium<br>Calcium<br>Cerium<br>Chromium<br>Cobalt<br>Hafnium<br>Iridium<br>Iron<br>Lead<br>Lithium<br>Manganese<br>Nickel<br>Palladium<br>Platinum<br>Plutonium<br>Potassium<br>Rubidium<br>Sodium<br>Tantalum<br>Thorium<br>Titanium<br>Uranium<br>Zirconium | <b>Pyrophoric alkyl non-metals</b><br>Bis(dibutylborino) acetylene<br>Bis-dimethylarsinyl oxide<br>Bis-dimethylarsinyl sulphide<br>Bis-trimethylsilyl oxide<br>Dibutyl-3-methyl-3-buten-1-ynborane<br>Diethoxydimethylsilane<br>Diethylmethylphosphine<br>Ethyldimethylphosphine<br>Tetraethyldiarsine<br>Tetramethyldiarsine<br>Tetramethylsilane<br>Tribenzylarsine<br>mixo-Tributylborane<br>Tributylphosphine                                                                                                                                                                                                                                                                     | <b>Pyrophoric alkyl non-metal halides</b><br>Butyldichloroborane<br>Dichlorodiethylsilane<br>Dichlorodimethylsilane<br>Dichloro(ethyl)silane<br>Dichloro(methyl)silane<br>Iododimethylarsine<br>Trichloro(ethyl)silane<br>Trichloro(methyl)silane<br>Trichloro(vinyl)silane<br><br><b>Pyrophoric alkyl non-metals</b><br><b>Hydrides</b><br>Diethylarsine<br>Diethylphosphine<br>Dimethylarsine<br>1,1-Dimethyldiborane<br>1,2-Dimethyldiborane<br>Dimethylphosphine<br>Ethylphosphine<br>Methylphosphine<br>Methylsilane |
| <b>Pyrophoric carbonyl metals</b><br>Carbonyllithium                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>Pyrophoric non-metals and metal carbides</b><br>Phosphorus<br>Silane<br>Phosphine<br>Calcium carbide<br>Uranium carbide                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

**Table 6.10 Electrochemical series**

| <i>Metal</i> | <i>Symbol</i> | <i>Electro-negativity</i> | <i>Occurrence</i>                    | <i>Reactivity with water</i>                                  |
|--------------|---------------|---------------------------|--------------------------------------|---------------------------------------------------------------|
| Lithium      | Li            | 0.97                      | Never found uncombined               | React with cold water to yield hydrogen                       |
| Caesium      | Cs            | 0.86                      |                                      |                                                               |
| Potassium    | K             | 0.91                      |                                      |                                                               |
| Barium       | Ba            | 0.97                      |                                      |                                                               |
| Strontium    | Sr            | 0.99                      |                                      |                                                               |
| Calcium      | Ca            | 1.04                      |                                      |                                                               |
| Sodium       | Na            | 1.01                      |                                      |                                                               |
| Magnesium    | Mg            | 1.23                      | Rarely found uncombined              | Burning metals decompose water and hot metals decompose steam |
| Aluminium    | Al            | 1.47                      |                                      |                                                               |
| Manganese    | Mn            | 1.60                      |                                      |                                                               |
| Zinc         | Zn            | 1.66                      |                                      |                                                               |
| Chromium     | Cr            | 1.56                      |                                      |                                                               |
| Iron         | Fe            | 1.64                      |                                      |                                                               |
| Cadmium      | Cd            | 1.46                      |                                      |                                                               |
| Cobalt       | Co            | 1.70                      |                                      |                                                               |
| Nickel       | Ni            | 1.75                      |                                      | Very little reaction unless at white heat                     |
| Tin          | Sn            | 1.72                      |                                      |                                                               |
| Lead         | Pb            | 1.55                      |                                      |                                                               |
| Hydrogen     | H             | 2.20                      |                                      |                                                               |
| Phosphorus   | P             | 2.06                      | Sometimes found uncombined           | Inactive with water or steam                                  |
| Oxygen       | O             | 3.50                      |                                      |                                                               |
| Bismuth      | Bi            | 1.67                      |                                      |                                                               |
| Copper       | Cu            | 1.75                      |                                      |                                                               |
| Mercury      | Hg            | 1.44                      |                                      |                                                               |
| Silver       | Ag            | 1.42                      |                                      |                                                               |
| Platinum     | Pt            | 1.44                      | Found uncombined with other elements |                                                               |
| Gold         | Au            | 1.42                      |                                      |                                                               |

Other types of explosion involve,

Pressure rupture, due to rapid release of high pressure. Blast is generated by rapid expansion of gas down to atmospheric pressure and rupture of the container generates missiles.

Steam explosion: rapid vaporization of water within molten metal, molten salts or hot oil or through them contacting surface or adsorbed moisture (refer to page 47).

The last two types do not involve a combustion reaction but the damage they cause can similarly be related to the overpressure generated at a given distance from the event.

## Control measures

### *Strategies for handling flammable materials*

Minimize *at the design stage* the risk of fire/explosion, e.g. by substitution with a less volatile chemical or operation at lower temperature, avoidance of air ingress or use of inerting. Design to minimize leakages and avoidance of potential ignition sources.

Minimize the risk by *appropriate systems of work*.

Mitigate *the effects of fire or explosion*, e.g. by detection provision, spacing, appropriate construction materials, shielding, venting, extinguishment, provision for evacuation of personnel.

### ***Fire prevention***

Theoretically, if one corner of the ‘fire triangle’ is eliminated a fire or explosion is impossible. However, in practice, if flammable gases or vapours are mixed with air in flammable concentrations, sooner or later the mixture is likely to catch fire or explode because of the difficulty of eliminating every source of ignition. For reliable control of flammable materials, including combustible dusts, the aim is to remove *two* corners from the fire triangle. This can include some combination of:

Prevention of a mixture forming within the flammable range.

Elimination of ignition sources (see Table 6.3).

### ***Fire control***

Fire detection and suppression form the basis of fire control, with emergency back-up procedures to mitigate the consequences. Selected key tactics for working with flammable chemicals are summarized in Table 6.11.

Refer also to ‘Fire extinguishment’ (page 221).

### ***Dust explosions***

The avoidance, and mitigation of the effects, of a dust explosion may involve some combination of:

Elimination of ignition sources, which is inherently difficult to ensure.

Atmosphere control, e.g. controlling dust concentrations or inerting.

Containment of explosion overpressure, i.e. by designing plant capable of withstanding in excess of the maximum explosion overpressure, or safe venting of forces, e.g. via blow-off panels, doors, membranes.

Limitation of inventory.

Restriction of spread by means of baffles, chokes or by advance inerting.

Use of water sprays or very rapid injection of suppressant gas or powder.

Good housekeeping, particularly to avoid a devastating secondary explosion, following redispersion of any accumulations of combustible dust.

A similar logic is applicable to the control of explosions involving gas or vapour, but other measures, e.g. dispersion by steam or containment by water curtains, may be applicable to vapour clouds in the open air. Containment or diversion of a blast (e.g. by blast walls) and reducing its effect by appropriate spacing of equipment, buildings etc. are also applicable.

### ***Pyrophorics***

Control measures to reduce the risk from handling pyrophorics include:

Handling and storing the minimum quantities necessary at any time.

**Table 6.11 Control measures for working with flammable chemicals**


---

|                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Substitute with less volatile/flammable material where possible (i.e. higher flash point/autoignition temperature, lower vapour pressure)                                                                                                                                                                                                                                                       |
| Check on legal requirements and relevant standards/codes etc.                                                                                                                                                                                                                                                                                                                                   |
| Minimize quantities in use/in store                                                                                                                                                                                                                                                                                                                                                             |
| Keep below LEL, e.g. chill to lower airborne concentration, use exhaust ventilation, inerting, keep air out.                                                                                                                                                                                                                                                                                    |
| Design plant/equipment so as to contain the material and provide adequate dilution or exhaust ventilation as appropriate                                                                                                                                                                                                                                                                        |
| Provide means to contain spillages, e.g. bund walls, kerbs                                                                                                                                                                                                                                                                                                                                      |
| Eliminate ignition sources                                                                                                                                                                                                                                                                                                                                                                      |
| Eliminate static                                                                                                                                                                                                                                                                                                                                                                                |
| Consider need for inerting, flame arresters, pressure relief valves, explosion vents (venting to safe location)                                                                                                                                                                                                                                                                                 |
| Consider need for checks on oxygen levels or loss of inert medium                                                                                                                                                                                                                                                                                                                               |
| Apply appropriate zoning criteria, e.g. with respect to standards of electrical equipment (refer to Table 12.6)                                                                                                                                                                                                                                                                                 |
| Set up procedures to prevent inadvertent introduction of other ignition sources and to avoid oxygen enrichment: <ul style="list-style-type: none"> <li>Physical segregation, e.g. fences</li> <li>Warning signs to indicate flammable hazard, no smoking etc.</li> <li>Permits-to-work (including hot work permits)</li> <li>Safe systems of work to control plant modifications etc</li> </ul> |
| Keep flammable chemicals apart from oxidizing agents                                                                                                                                                                                                                                                                                                                                            |
| Design layout to avoid domino effects/fire spread                                                                                                                                                                                                                                                                                                                                               |
| Segregate 'empty' and 'full' containers                                                                                                                                                                                                                                                                                                                                                         |
| Check for plant integrity/flammable leaks periodically or continuously on-line, as appropriate                                                                                                                                                                                                                                                                                                  |
| Install appropriate fire/smoke detection, audible alarms                                                                                                                                                                                                                                                                                                                                        |
| Provide adequate fire suppression systems                                                                                                                                                                                                                                                                                                                                                       |
| Deal with mishaps such as spillage immediately                                                                                                                                                                                                                                                                                                                                                  |
| Train staff in hazards and precautions, and practise emergency evacuation drills                                                                                                                                                                                                                                                                                                                |
| Remember that flammable chemicals can also be <i>toxic</i> or <i>asphyxiant</i>                                                                                                                                                                                                                                                                                                                 |

---

Segregation of the material from other chemicals, particularly 'fuels', i.e. solvents, paper, cloth etc.

Handling in dry, chemically-inert atmospheres or beneath other appropriate media, e.g. dry oil or inert gas.

Handling in solution (e.g. aluminium alkyls in petroleum solvents).

Immediate destruction and removal of spilled materials.

Careful selection and provision of appropriate fire extinguishers in advance.

Provision and use of appropriate eye/face protection, overalls and gloves.

## Fire extinguishment

### *Detection*

If a flammable gas or vapour is present, a pre-fire condition may be identified by a flammable-gas detector. This will actuate an alarm at a fraction of the LFL. Banks of detectors may be installed at high or low level depending, in part, upon the gas density. Fire detection may be by:

Personnel, e.g. operating, maintenance or security staff, or neighbours, or passers-by.  
 Heat sensing, as actual temperature or rate-of-temperature rise, and depending upon melting of a metal (fusion); expansion of a solid, liquid or gas; electrical sensing.  
 Smoke detection depending upon absorption of ionizing radiation by smoke particles; light scattering by smoke particles; light obscuration.  
 Flame detection by ultraviolet radiation or infra-red radiation sensing.

A combination of detectors may be appropriate. They may activate an alarm only, or actuate a combined alarm/extinguishment system. With a bank of detectors a voting system may be used to increase reliability and reduce the frequency of spurious alarms. Detection/alarm systems may also be interlinked with, e.g., fire-check doors held back on electromagnetic catches such that the doors close automatically upon activation of the detection system.

## ***Extinguishment***

Removal of one of the corners of the fire triangle normally results in extinguishment of a fire. Propagation of a flame can also be stopped by inhibition of the chain reactions, e.g. using dry powders or organo-halogen vaporizing liquids.

### *Classification of fires*

| <i>Class</i> | <i>Type</i>                                                                                                                                 |
|--------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| A            | Fire involving solid materials, generally organic materials, in which combustion normally takes place with the formation of glowing embers. |
| B            | Fire involving a liquid or liquefiable solid (the miscibility or otherwise with water is an important characteristic).                      |
| C            | Fire involving a gas.                                                                                                                       |
| D            | Fire involving a burning metal, e.g. magnesium, aluminium, sodium, calcium or zirconium.                                                    |

An additional class not currently included in British Standard EN2 is Class F fires including cooking oils or fats. Electrical fires are not classified since any fire involving, or initiated by, electrical equipment will fall within Class A, B or C.

### *Fire-extinguishing materials*

The penetration and cooling action of *water* is required with Class A fires, e.g. those involving paper, wood, textiles, refuse. Water is applied in the form of a jet or spray; foam or multi-purpose powder extinguishers are alternatives. Extinguishment of a Class B fire can be achieved by the smothering action of dry chemical, carbon dioxide or foam. Most flammable liquids will float on water (refer to Table 6.1 under 'Specific gravity'), so that water as a jet is unsuitable: a mist may, however, be effective. Water is also widely used to protect equipment exposed to heat. Dry powders are effective on flammable liquid or electrical fires.

*Foam* is a proportioned mixture of water and foam concentrate aspirated with air to cause expansion, e.g. from 6 to 10 times the volume (low expansion foam) up to >100 times (high expansion foam). It transports water to the surface of flammable liquids and enables it to float and extinguish the fire. An effective system depends upon:

The type of flammable liquid – determines the type of foam, e.g. standard or alcohol-resistant grade. Aqueous film-forming foam may be used for rapid 'knock-down'.



The type of hazard – determines the method and rate of application, e.g. by fixed pourers, mobile monitors, portable foam-towers or fixed semi-subsurface systems.

The size of the hazard – determines the requirements for foam concentrate and water.

*Carbon dioxide* is useful where the minimum damage should be caused to the materials at risk, on fires in liquid, solids or electrical fires but not where there is a high risk of reignition. It is likely to be ineffective outdoors due to rapid dispersal. It is unsuitable for reactive metals, metal hydrides or materials with their own oxygen supply, e.g. cellulose nitrate.

*Dry powders* are effective on flammable liquid or electrical fires. Special powders are available for use on metals. Dry powder extinguishers may be used on Class C fires, including gases and liquefied gases in the form of a liquid spillage or a liquid or gas leak. This must be accompanied by other actions, e.g. stopping the leak; this is necessary to avoid accumulation of an unburned flammable gas-air mixture which could subsequently result in an explosion. Activation may be automatic by a detection system, or manual.

*Vaporizing liquid halogen* agents are electrically non-conductive and are effective on a wide range of combustibles, particularly flammable liquids and electrical fires. A 'lock-off' system is required on fixed installations to protect personnel, the normal extinguishing concentration being 5% by volume. The use of such liquids is being phased out; except for defined essential uses they will be banned from 31 December 2003.

*Portable extinguishers* and *fire blankets* are normally provided at strategic points in the work area. The range of application of portable extinguishers is summarized in Table 6.12. British Standard EN3: Part 5 requires all new extinguisher bodies to be red. A zone of colour above, or within, the section used to provide operating instructions may be used to identify the type of extinguisher. The colours used are:

|                                                 |       |
|-------------------------------------------------|-------|
| Standard dry powder or multi-purpose dry powder | blue  |
| AFFF (aqueous film-forming foam)                | cream |
| Water                                           | red   |
| Vaporizing liquid, including Halon              | green |
| Carbon dioxide                                  | black |

Fixed installations for fire-fighting may be either:

Manually operated for general protection, e.g. hose reels, hydrants and foam installations, or  
Automatically operated for general protection, e.g. sprinklers, or for special-risk protection, e.g. carbon dioxide installations.

The general requirements of such an installation are summarized in Table 6.13.

## Fire precautions

A range of precautions are based on the principles summarized earlier. However, general precautions, applicable to the majority of work situations, are listed in Table 6.14, many of which are included in legal requirements. In the UK duties under the Fire Precautions (Workplace) (Amendment) Regulations 1999 are to:

- carry out a fire risk assessment of the workplace;
- identify significant findings and details of anyone specifically at risk;

**Table 6.12 Portable fire extinguishers**

| <i>Extinguisher type</i>                                                                                                             | <i>Water</i>  | <i>Carbon dioxide</i> | <i>Dry powder</i> | <i>Foam</i>                  | <i>Vaporizing liquid<sup>(3)</sup></i> | <i>Fire blanket</i>                               | <i>Sand</i>      |
|--------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------------------|-------------------|------------------------------|----------------------------------------|---------------------------------------------------|------------------|
| <b>Class A fire</b><br>Wood, cloth, paper<br>or similar<br>combustible<br>material<br><i>Cooling by water<br/>most effective</i>     | Most suitable | Small fires only      | Small fires only  | Yes                          | Small fires only <sup>(1)</sup>        | No, except for<br>personal<br>clothing on<br>fire | No               |
| <b>Class B fire</b><br>Flammable liquids,<br>petrol, oils,<br>greases, fats<br><i>Blanketing/<br/>smothering most<br/>effective</i>  | Dangerous     | Most suitable         | Most suitable     | Most suitable <sup>(2)</sup> | Small fires only <sup>(1)</sup>        | Most suitable<br>Small fires only                 | Small fires only |
| <b>Electrical plant,</b><br>electrical<br>installations<br><i>Non-conductivity<br/>of extinguishing<br/>agent most<br/>important</i> | Dangerous     | Most suitable         | Most suitable     | No                           | Yes <sup>(1)</sup>                     | No                                                | No               |

<sup>(1)</sup> Toxic products may be produced: care must be exercised after use in confined spaces.

<sup>(2)</sup> Special foam required for water-miscible liquids.

<sup>(3)</sup> Subject to replacement.

**Table 6.13 General requirements for fixed fire-extinguishing systems (Activation may be automatic by a detection system, or manual)**


---

|                                                                                                                                                                               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Capability to control and extinguish the anticipated fire condition without recourse to outside assistance (unless planned for).                                              |
| Reliability, allowing for environmental features likely to be detrimental to operation, e.g. dust, corrosion, tar.                                                            |
| Agents must be compatible with the process, with each other, and with any other installed systems.                                                                            |
| Consideration of the potential toxicity of the agent, any thermal degradation products, or products generated on contact with chemicals present will dictate safety measures. |
| If manual fire-fighting is also anticipated following agent discharge, visibility in the fire zone requires consideration.                                                    |

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**Table 6.14 General fire precautions**


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|                                  |                                                                                                                                                                                                                                                                                                |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Area designation</b>          | Zoning for electrics<br>Control portable heaters etc.<br>No smoking<br>Restricted areas                                                                                                                                                                                                        |
| <b>Electrical equipment</b>      | Regular inspection and maintenance by qualified electricians<br>Prohibition of makeshift installations                                                                                                                                                                                         |
| <b>Waste disposal</b>            | Prevention of combustible waste accumulation in corners, passageways or other convenient 'storage' areas                                                                                                                                                                                       |
| <b>Storage</b>                   | Segregated storage<br>Uncongested storage of combustibles: gangways/adequate breaks<br>Material stacked in the open should be away from windows<br>Flammable liquids in properly designed storerooms: bulk quantities in fixed, banded, adequately spaced tanks                                |
| <b>Contractors</b>               | Clearance Certificate control of contractors/temporary workers<br>Close control of temporary heating, lighting, cooking etc.                                                                                                                                                                   |
| <b>Escape/access</b>             | Escape doors and routes must be kept free of obstructions<br>Access for emergency services must be maintained                                                                                                                                                                                  |
| <b>Fire equipment</b>            | Fire alarm and fire-fighting equipment must be regularly inspected, maintained and tested<br>Portable extinguishers to have designated locations/be of correct type. Instructions must be provided as to where and how to use them. Practice is necessary                                      |
| <b>Flues</b>                     | Passages for services or other ducts must be adequately fire-stopped to prevent their acting as flues for fire/smoke transmission                                                                                                                                                              |
| <b>Sprinklers</b>                | Maintain sprinkler systems<br>Institute alterations if building is modified, use changes etc.<br>Observe use specifications, e.g. for stack heights, fire loading                                                                                                                              |
| <b>Prevention of arson</b>       | Control access at all times<br>Screen employees and casual labour<br>Lock away flammable substances and keep combustibles away from doors, windows, fences<br>Provide regular fire safety patrols, even where automatic systems are provided<br>Secure particularly storage and unmanned areas |
| <b>Fire and smoke stop doors</b> | Ensure that fireproof doors and shutters are self-closing<br>Keep <i>all</i> doors free from obstruction<br>Ensure that fire check doors are kept closed                                                                                                                                       |

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provide and maintain fire precautions to safeguard those at the workplace;  
provide relevant information, instruction and training.

In the UK the Building Regulations impose fire safety requirements on:

structural stability;  
compartmentalization to restrict fire spread;  
fire resistance of elements and structures;  
reduction of spread of flame over surfaces of walls and ceilings;  
space separation between buildings to reduce the risk of fire spread from one building to another;  
means of escape in case of fire;  
access for fire appliances and assistance to the fire brigade.

An action plan for risk assessment is given in Figure 6.2.

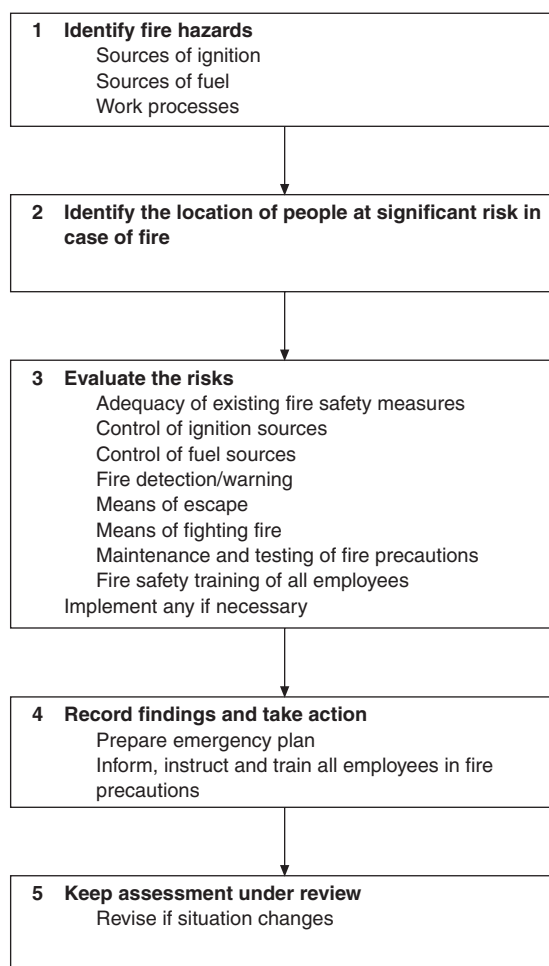


**Figure 6.2** Action plan for fire risk assessment

The minimum fire instruction and training needs are summarized in Table 6.15.

**Table 6.15 Essentials for fire instruction and training**

---

|                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------|
| Action to be taken upon discovering a fire                                                                                         |
| Action to be taken upon hearing the fire alarm                                                                                     |
| Raising the alarm, including the location of alarm call points, internal fire alarm telephones and alarm indicator panels          |
| Correct method of calling the fire service                                                                                         |
| The location and use of fire-fighting equipment                                                                                    |
| Knowledge of the escape routes                                                                                                     |
| The importance of fire doors and the need to close all doors at the time of a fire and on hearing the fire alarm                   |
| Stopping machines and processes and isolating power supplies where appropriate                                                     |
| Evacuation of the building:                                                                                                        |
| procedures for alerting visitors, members of the public etc., including if necessary directing/escorting them to exits;            |
| familiarity with how to open all escape doors and the use of any emergency fastenings;                                             |
| understanding of the reason for not using lifts except those designated, and of special design, for evacuation of disabled persons |

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**Table 6.1 Properties of flammable chemicals**

| <i>Substance</i>                               | <i>Specific gravity</i> | <i>Vapour density (air = 1)</i> | <i>Flash point<sup>(1)</sup> (°C)</i> | <i>Ignition temp. (°C)</i> | <i>Flammable limits<sup>(1)</sup> (%)</i> | <i>Boiling point (°C)</i> | <i>Melting point (°C)</i> | <i>Solubility in water (g/100 g)</i> | <i>Vapour pressure (mm Hg/ °C)</i> |
|------------------------------------------------|-------------------------|---------------------------------|---------------------------------------|----------------------------|-------------------------------------------|---------------------------|---------------------------|--------------------------------------|------------------------------------|
| Acetal                                         | 0.83                    | 4.08                            | −21                                   | 230                        | 1.6–10.4                                  | 103                       | −100                      | 21 <sup>20</sup>                     | 10/8                               |
| Acetaldehyde                                   | 0.78                    | 1.52                            | −38                                   | 185                        | 4–57                                      | 21                        | −124                      | ∞                                    | –                                  |
| Acetanilide                                    | 1.21                    | 4.7                             | 174                                   | 546                        | –                                         | 304                       | 114                       | –                                    | 1/114                              |
| Acetic acid                                    | 1.05                    | 2.1                             | 43                                    | 426                        | 4–16                                      | 118                       | 17                        | ∞                                    | 11.4/20                            |
| Acetic anhydride                               | 1.08                    | 3.5                             | 54                                    | 385                        | 3–10                                      | 140                       | −73                       | ∞                                    | 10/36                              |
| Acetone                                        | 0.79                    | 2.0                             | −18                                   | 538                        | 3–13                                      | 56                        | −94                       | ∞                                    | 400/40                             |
| Acetone cyanohydrin                            | 0.93                    | 2.9                             | 74                                    | 688                        | –                                         | 82                        | −19                       | v. sol                               | –                                  |
| Acetonitrile                                   | 0.79                    | 1.4                             | 6                                     | 524                        | 4–16                                      | 80                        | −45                       | ∞                                    | 100/27                             |
| Acetyl acetone, see 2,4-Pentanedione           |                         |                                 |                                       |                            |                                           |                           |                           |                                      |                                    |
| Acetyl chloride                                | 1.1                     | 2.7                             | 4                                     | 390                        | –                                         | 51                        | −112                      | dec.                                 | –                                  |
| Acetylene                                      | 0.91                    | 0.9                             | –                                     | 300                        | 3–82                                      | −83                       | Subl.                     | sl. sol.                             | 40 atm/17                          |
| Acetylene dichloride, see 1,2-Dichloroethylene |                         |                                 |                                       |                            |                                           |                           |                           |                                      |                                    |
| Acetyl peroxide                                | 1.2                     | 4.07                            | 113oc                                 | –                          | –                                         | 63exp.                    | 30                        | sl. sol.                             | –                                  |
| Acrolein                                       | 0.84                    | 1.9                             | −26                                   | 278                        | 3–31                                      | 53                        | −87                       | v. sol.                              | –                                  |
| Acrolein dimer                                 | 1.1                     | –                               | 48                                    | –                          | –                                         | 151                       | −73                       | sol.                                 | –                                  |
| Acrylic acid                                   | 1.05                    | 2.5                             | 52oc                                  | 429                        | –                                         | 142                       | 12                        | ∞                                    | 10/39                              |
| Acrylonitrile                                  | 0.81                    | 1.8                             | 0oc                                   | 481                        | 3–17                                      | 77                        | −83                       | sol.                                 | 100/23                             |
| Adipic acid                                    | 1.4                     | 5.04                            | 191                                   | 422                        | –                                         | 334                       | 153                       | sl. sol.                             | 1/160                              |
| Adiponitrile                                   | 0.97                    | 3.73                            | 93                                    | –                          | –                                         | 295                       | 2.3                       | sl. sol.                             | –                                  |
| Aerозine 50, see Hydrazine                     |                         |                                 |                                       |                            |                                           |                           |                           |                                      |                                    |
| Aldrin                                         | –                       | –                               | 66                                    | –                          | –                                         | –                         | 104                       | insol.                               | –                                  |
| Allyl acetate                                  | 0.93                    | 3.4                             | 21oc                                  | 374                        | –                                         | 103                       | –                         | sl. sol.                             | –                                  |
| Allyl alcohol                                  | 0.85                    | 2.0                             | 21                                    | 378                        | 3–18                                      | 97                        | −129                      | ∞                                    | 10/10                              |
| Allyl amine                                    | 0.76                    | 2.0                             | −29                                   | 374                        | 2–22                                      | 55                        | –                         | ∞                                    | –                                  |
| Allyl bromide                                  | 1.4                     | 4.2                             | −1                                    | 295                        | 4–7                                       | 70                        | −119                      | insol.                               | –                                  |
| Allyl chloride                                 | 0.94                    | 2.6                             | −32                                   | 392                        | 3–11                                      | 45                        | −136                      | insol.                               | –                                  |
| Allyl chloroformate                            | 1.1                     | 4.2                             | 31                                    | –                          | –                                         | 110                       | –                         | insol.                               | –                                  |
| Allylene, see Propyne                          |                         |                                 |                                       |                            |                                           |                           |                           |                                      |                                    |
| Allyl glycidyl ether                           | 0.97                    | 3.4                             | 57                                    | –                          | –                                         | 154                       | −100                      | sol.                                 | –                                  |
| 2-Aminoethanol, see Ethanolamine               |                         |                                 |                                       |                            |                                           |                           |                           |                                      |                                    |
| Aminoethylethanol amine                        | 1.03                    | 3.6                             | 129                                   | 368                        | –                                         | 244                       | –                         | v. sol                               | –                                  |
| Ammonia, anhydrous                             | 0.77                    | 0.59                            | –                                     | 651                        | 16–25                                     | −33                       | −78                       | 89.9                                 | 10 atm/26                          |
| Ammonium nitrate                               | 1.7                     | –                               | –                                     | –                          | exp.                                      | 210/11 mm dec.            | 169                       | 118                                  | –                                  |
| <i>n</i> -Amyl acetate                         | 0.88                    | 4.5                             | 25                                    | 379                        | 1–7.5                                     | 148                       | −79                       | sl. sol.                             | –                                  |
| iso-Amyl acetate                               | 0.88                    | 4.5                             | 23                                    | 380                        | 1–7.5                                     | 142                       | –                         | –                                    | –                                  |
| sec-Amyl acetate                               | 0.86                    | 4.5                             | 32                                    | –                          | 1–7.5                                     | 121                       | –                         | –                                    | –                                  |

[illegible]

Table 6.1 Cont'd

| Substance                             | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|---------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| Bromoethane                           | 1.46             | 3.76                     | none                            | 511                 | 6.7–11.3                            | 38                 | –119               | sl. sol.                      | 400/21                      |
| Bromomethane, see Methyl bromide      |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Bromopentane, see Amyl bromide        |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Bromopropane, see Propyl bromide      |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| 3-Bromopropene, see Allyl bromide     |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| 3-Bromopyne, see Propargyl bromide    |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| o-Bromotoluene                        | 1.42             | 5.9                      | 79                              | –                   | –                                   | 181                | –27                | insol.                        | –                           |
| 1,3-Butadiene                         | 0.62             | 1.97                     | <–7                             | 429                 | 2–11.5                              | –4.7               | –109               | insol.                        | 1840/21                     |
| n-Butane                              | 0.60             | 2.04                     | –60                             | 405                 | 1.9–8.5                             | –0.5               | –138               | v. sol.                       | 2 atm/19                    |
| iso-Butane                            | 0.56             | 2.01                     | –                               | 462                 | 1.8–8.4                             | –12                | –160               | sol.                          |                             |
| n-Butanol, see n-Butyl alcohol        |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Butanone, see Methyl ethyl ketone     |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| 1-Butene                              | 0.60             | 1.9                      | –80                             | 384                 | 1.6–9.3                             | –6.1               | –130               | insol.                        | 3480/21                     |
| 2-Butene                              | 0.62             | 1.9                      | –                               | 324                 | 1.8–9.0                             | 1.1                | –127               | insol.                        | 1410/21                     |
| 2-Butene (trans)                      | 0.6              | 2.0                      | –73                             | 324                 | 2–10                                | 2.5                | –106               | –                             | 1592/21                     |
| 2-Butoxyethanol, see Butyl cellosolve |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| n-Butyl acetate                       | 0.88             | 4.0                      | 27                              | 399                 | 1.4–7.6                             | 125                | –76                | sl. sol.                      | 15/25                       |
| iso-Butyl acetate                     | 0.87             | 4.0                      | 18                              | 423                 | 1.3–7.5                             | 117                | –99                | sl. sol.                      | –                           |
| sec-Butyl acetate                     | 0.86             | 4.0                      | 31                              | –                   | 1.7–                                | 112                | –                  | insol.                        | 24                          |
| Butyl acetyl ricinoleate              | 0.9              | 13.7                     | 110                             | 385                 | –                                   | 220                | –32                | –                             | –                           |
| Butyl acrylate                        | 0.9              | 4.4                      | 49 <sup>oc</sup>                | –                   | –                                   | 69.50 mm           | –65                | –                             | 10/36                       |
| n-Butyl alcohol                       | 0.81             | 2.55                     | 29                              | 365                 | 1.4–11                              | 118                | –89                | sol.                          | 6/20                        |
| iso-Butyl alcohol                     | 0.81             | 2.55                     | 28                              | 427                 | 1.7–10.9                            | 107                | –108               | 10 <sup>15</sup>              | –                           |
| sec-Butyl alcohol                     | 0.81             | 2.55                     | 24                              | 406                 | 1.7–9.8                             | 99.5               | –115               | 12.5                          | 10/20                       |
| tert-Butyl alcohol                    | 0.78             | 2.55                     | 10                              | 478                 | 2.4–8                               | 83                 | 25                 | ∞                             | 40/25                       |
| Butylamine                            | 0.76             | 2.5                      | –12                             | 312                 | 1.7–9.8                             | 78                 | –50                | ∞                             | 72/20                       |
| tert-Butylamine                       | 0.70             | 2.5                      | –                               | –                   | 1.7–8.9                             | 45                 | –67                | ∞                             | –                           |
| iso-Butylamine                        | 0.73             | 2.5                      | –9                              | 378                 | –                                   | 66                 | –104               | ∞                             | –                           |
| n-Butyl benzene                       | 0.9              | 4.6                      | 71                              | 412                 | 1–6                                 | 182                | –81                | –                             | 1/23                        |
| iso-Butyl benzene                     | 0.9              | 4.6                      | 52                              | 418                 | 1–7                                 | 174                | –83                | –                             | 1/19                        |
| n-Butyl bromide                       | 1.28             | 4.7                      | 18                              | 265                 | 2–6.6                               | 101                | –112               | 0.06                          | –                           |
| Butyl carbitol                        | 1.0              | 5.6                      | 78                              | 228                 | –                                   | 231                | –68                | –                             | 0.02/20                     |
| Butyl carbitol acetate                | 1.0              | –                        | 116                             | 299                 | –                                   | 247                | –32                | –                             | <0.01/20                    |



[illegible]

Table 6.1 Cont'd

| Substance                                             | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|-------------------------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| Carbonyl sulphide                                     | 1.07             | 2.1                      | –                               | –                   | 12–29                               | –50                | –138               | 80 <sup>14</sup>              |                             |
| Carvene, <i>see</i> Dipentene                         |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Cellosolve                                            | 0.93             | 3.10                     | 41                              | 238                 | 1.7–15.6                            | 135                | –                  | ∞                             | 3.8/20                      |
| Cellosolve acetate                                    | 0.97             | 4.7                      | 55                              | 382                 | 1.2–12.7                            | 156                | –62                | v. sol.                       | 1.2/20                      |
| Cellulose nitrate                                     | 1.66             | –                        | 13                              | –                   | –                                   | –                  | –                  | insol.                        | –                           |
| Chloral                                               | 1.51             | 5.1                      | none                            | –                   | –                                   | 98                 | –58                | v. sol.                       | –                           |
| Chlordane                                             | ~1.6             | –                        | 56                              | –                   | –                                   | 175                | –                  | –                             | –                           |
| Chlorine dioxide                                      | 3.09             | 2.3                      | –                               | 100                 | –                                   | 9.9                | –59                | dec.                          | –                           |
| Chloroacetaldehyde                                    | 1.19             | 2.7                      | 88                              | –                   | –                                   | 85                 | –16                | –                             | 100/45<br>(40% solution)    |
| Chlorobenzene                                         | 1.11             | 3.9                      | 29                              | 638                 | 1.3–7.1                             | 132                | –45                | insol.                        | 10/22                       |
| 1-Chloro-1,1-difluoroethane                           | 1.12             | –                        | –                               | 632                 | 9–14.8                              | –9.2               | –                  | –                             | –                           |
| 1-Chloro-2,4-dinitrobenzene                           | 1.7              | –                        | 194                             | 432                 | 2–22                                | 315                | 43                 | insol.                        | –                           |
| Chlorodiphenyls                                       | ~1.4             | –                        | 176–80                          | –                   | –                                   | 340–75             | –                  | –                             | 30/200                      |
| 1-Chloro-2,3-epoxypropane, <i>see</i> Epichlorohydrin |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Chloroethane, <i>see</i> Ethyl chloride               |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Chloroethanol, <i>see</i> Ethylene chlorohydrin       |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Chloromethane, <i>see</i> Methyl chloride             |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Chloronaphthalene                                     | 1.19             | 5.6                      | 132                             | >558                | –                                   | 256                | –20                | insol.                        | –                           |
| Chloronitrobenzenes                                   | 1.37             | –                        | 127                             | –                   | –                                   | 242                | 32–46              | insol.                        | –                           |
| 1-Chloro-1-nitropropane                               | 1.21             | 4.3                      | 62                              | –                   | –                                   | 142                | –                  | sl. sol.                      | –                           |
| <i>o</i> -Chlorophenol                                | 1.24             | –                        | 64                              | –                   | –                                   | 175                | 7                  | v. sol.                       | 1/12                        |
| <i>p</i> -Chlorophenol                                | 1.24             | –                        | 121                             | –                   | –                                   | 220                | 43                 | sol.                          | 1/49                        |
| <i>o</i> -Chlorophenyl diphenyl phosphate             | 1.3              | 12.5                     | >215                            | –                   | –                                   | 240–55/5 mm        | <0                 | –                             | –                           |
| Chloroprene                                           | 0.95             | 3.0                      | –20                             | –                   | 4–20                                | 59                 | –                  | sl. sol.                      | –                           |
| Chlorotrifluoroethylene                               | 1.31             | –                        | –27                             | –                   | 8.4–39                              | –28                | 158                | –                             | –                           |
| Cinnamaldehyde                                        | 1.05             | –                        | 49                              | –                   | –                                   | 253                | –7.5               | sl. sol.                      | –                           |
| <i>m</i> -Cresol                                      | 1.03             | 3.7                      | 94                              | 559                 | 1.06–1.35                           | 203                | 12                 | sol.                          | 1/52                        |
| <i>o</i> -Cresol                                      | 1.05             | 3.7                      | 81                              | 599                 | 1.35–                               | 191                | 31                 | sol. (hot)                    | 1/38                        |
| <i>p</i> -Cresol                                      | 1.04             | 3.7                      | 94                              | 559                 | 1.06–1.4                            | 202                | 35                 | sol. (hot)                    | –                           |
| Creosote (mixed phenols)                              | 1.07             | –                        | 74–82                           | 336                 | –                                   | 200–250            | –                  | –                             | –                           |
| Cresylic acid, <i>see</i> <i>o</i> -Cresol            |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Crotonaldehyde                                        | 0.87             | 2.4                      | 13                              | 207                 | 2.1–15.5                            | 104                | –76                | v. sol.                       | –                           |
| Crotonitrile                                          | 0.83             | 2.3                      | <100                            | –                   | –                                   | 110–116            | –52                | –                             | –                           |
| Crude oil (petroleum)                                 | 0.78–0.97        | –                        | (–7)–(+32)                      | –                   | –                                   | –                  | <–46               | –                             | –                           |

|                                        |      |      |      |         |          |           |      |                   |        |
|----------------------------------------|------|------|------|---------|----------|-----------|------|-------------------|--------|
| Cumene                                 | 0.86 | 4.1  | 44   | 424     | 0.9–6.5  | 152       | –96  | insol.            | 10/38  |
| Cumene hydroperoxide                   | 1.05 | –    | 79   | –       | –        | 153       | –    | –                 | –      |
| Cyanogen                               | 0.95 | 1.8  | –    | –       | 6–32     | –21       | –34  | 450 <sup>20</sup> | –      |
| Cyclohexane                            | 0.77 | 2.91 | –20  | 260     | 1.3–8.4  | 80        | 4.1  | insol.            | 100/60 |
| Cyclohexanol                           | 0.96 | 3.45 | 68   | 300     | –        | 161       | 25   | 3.6               | 1/21   |
| Cyclohexanone                          | 0.95 | 3.4  | 44   | 420     | 1.1–8.1  | 156       | –45  | sl. sol.          | 10/39  |
| Cyclohexene                            | 0.81 | 2.8  | <–6  | –       | –        | 83        | –104 | insol.            | 160/38 |
| Cyclohexylamine                        | 0.87 | 3.4  | 32   | 293     | –        | 135       | –18  | sol.              | –      |
| Cyclohexylbenzene                      | 0.95 | –    | 99   | 104     | –        | 238       | 7.5  | insol.            | 1/67   |
| Cyclopentane                           | 0.75 | 2.42 | –7   | –       | –        | 49        | –94  | insol.            | 400/31 |
| Cyclopentanone                         | 0.95 | 2.3  | 26   | –       | –        | 131       | –58  | insol.            | –      |
| Cyclopropane                           | 0.72 | 1.45 | –    | 498     | 2.4–10.4 | –33       | –127 | sl. sol.          | –      |
| <i>p</i> -Cymene                       | 0.86 | 4.62 | 47   | 436     | 0.7–5.6  | 177       | –68  | insol.            | 1/17   |
| Decaborane                             | 0.94 | –    | 80   | 149     | –        | 213       | 100  | sl. sol.          | 19/100 |
| Decahydronaphthalene                   | 0.87 | 4.76 | 57   | 250     | 0.7–4.9  | 186       | –45  | insol.            | –      |
| iso-Decaldehyde                        | 0.8  | 5.4  | 85   | –       | –        | 197       | –    | –                 | –      |
| Decalin, see<br>Decahydronaphthalene   |      |      |      |         |          |           |      |                   |        |
| <i>n</i> -Decane                       | 0.73 | 4.90 | 46   | 208     | 0.8–5.4  | 174       | –30  | insol.            | 1/17   |
| <i>n</i> -Decyl alcohol                | 0.83 | 5.3  | 82oc | –       | –        | 229       | 7    | insol.            | 1/170  |
| Diacetone alcohol                      | 0.93 | 4.0  | 64   | 603     | 1.8–6.9  | 168       | –50  | ∞                 | 1/20   |
| Diaminoethane, see Ethylene<br>Diamine |      |      |      |         |          |           |      |                   |        |
| Diazomethane                           | 1.45 | –    | –    | 100exp. | –        | –23       | –145 | dec.              | –      |
| Diborane                               | 0.46 | 0.96 | –90  | 145     | 0.9–98   | –93       | –165 | dec.              | –      |
| Dibutylamine                           | 0.50 | 4.46 | 52oc | –       | –        | 159       | –51  | sol.              | 2/20   |
| Dibutyldichlorotin                     | 1.36 | 10.5 | 355  | –       | –        | 135       | 43   | dec.              | –      |
|                                        |      |      |      |         |          | at 10 mm  |      |                   |        |
| Di- <i>n</i> -butyl ether              | 0.77 | 4.5  | 25   | 194     | 1.5–7.6  | 141       | –98  | insol.            | –      |
| Dibutyl oxalate                        | 1.01 | 7.0  | 104  | –       | –        | 246       | –30  | insol.            | –      |
| Dibutyl peroxide                       | 0.79 | 5.0  | 18   | –       | –        | 111       | –40  | insol.            | 20/20  |
| Dibutyl phosphite                      | 0.97 | 6.7  | 49   | –       | –        | 115       | –    | –                 | –      |
|                                        |      |      |      |         |          | at 10 mm  |      |                   |        |
| Dibutyl phthalate                      | 1.04 | 9.6  | 157  | 403     | –        | 340       | –35  | insol.            | –      |
| Dibutyl tartrate                       | 1.1  | –    | 91   | 284     | –        | 204/26 mm | 21   | –                 | –      |
| Dibutyl tin dilaurate                  | 1.05 | 21.8 | 235  | –       | –        | –         | 27   | insol.            | –      |
| Dichloroacetyl chloride                | 1.53 | 5.1  | 66   | –       | –        | 107       | –    | dec.              | –      |
| 2,5-Dichloroaniline                    | –    | 5.6  | 166  | –       | –        | 251       | 50   | sl. sol.          | –      |
| <i>o</i> -Dichlorobenzene              | 1.30 | 5.07 | 66   | 648     | 2–9      | 180       | –18  | insol.            | –      |

Table 6.1 Cont'd

| Substance                                     | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|-----------------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| 1,4-Dichlorobutane                            | 1.1              | 4.4                      | 52                              | –                   | –                                   | 162                | –39                | insol.                        | 4/20                        |
| 1,3-Dichloro-2-butene                         | –                | 4.3                      | 27                              | –                   | –                                   | 123                | –                  | insol.                        | –                           |
| 1,1-Dichloroethane                            | 1.18             | 3.4                      | –6                              | 458                 | 5.6–11.4                            | 57                 | –97                | 0.7                           | –                           |
| 1,2-Dichloroethane, see Ethylene dichloride   |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| 1,1-Dichloroethylene, see Vinylidene chloride |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| 1,2-Dichloroethylene                          | 1.3              | 3.3                      | 2–4                             | –                   | 9.7–12.8                            | 48–60              | –80                | sl. sol.                      | –                           |
| 2,2'-Dichloroethyl ether                      | 1.22             | 4.9                      | 55                              | 369                 | –                                   | 178                | –24                | insol.                        | –                           |
| Dichloromethane                               | 1.34             | 2.93                     | –                               | 662                 | 15.5–66 in O <sub>2</sub>           | 40                 | –97                | 2 <sup>20</sup>               | –                           |
| Dichloromonofluoromethane                     | 1.48             | 3.8                      | –                               | 552                 | –                                   | 9                  | –135               | insol.                        | –                           |
| 1,1-Dichloro-1-nitroethane                    | 1.42             | 4.97                     | 76                              | –                   | –                                   | 124                | –                  | 0.5 <sup>20</sup>             | –                           |
| Dichloropentanes (mixed)                      | 1.1              | 4.9                      | 41                              | 47                  | –                                   | 130                | –                  | –                             | –                           |
| 2,4-Dichlorophenol                            | 1.38             | 5.6                      | 114                             | –                   | –                                   | 210                | 45                 | sl. sol.                      | 1/53                        |
| 1,2-Dichloropropane                           | 1.16             | 3.9                      | 16                              | 557                 | 3.4–14.5                            | 97                 | –100               | sl. sol.                      | 40/19                       |
| 1,3-Dichloropropane                           | 1.23             | 3.8                      | 35                              | –                   | –                                   | 104                | –                  | insol.                        | –                           |
| Dicyclohexylamine                             | 0.93             | 6.3                      | 99oc                            | –                   | –                                   | 256                | –0.1               | 0.16 <sup>28</sup>            | –                           |
| Dicyclopentadiene                             | 0.93             | 4.55                     | 35                              | –                   | –                                   | 170                | 33                 | –                             | 10/48                       |
| Diethanolamine                                | 1.09             | 3.6                      | 152                             | 662                 | –                                   | 270                | 28                 | v. sol.                       | 5/188                       |
| 1,1-Diethoxyethane, see Acetal                |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Diethyladipate                                | 1.01             | –                        | –                               | –                   | –                                   | 240–5              | –21                | 0.43 <sup>30</sup>            | –                           |
| Diethylamine                                  | 0.71             | 2.5                      | <–26                            | 312                 | 1.8–10.1                            | 56                 | –48                | v. sol.                       | 400/38                      |
| 2-Diethyl-amino-ethanol                       | 0.88             | 4.03                     | 60                              | –                   | –                                   | 163                | –                  | ∞                             | –                           |
| N,N-Diethylaniline                            | 0.94             | 5.15                     | 85                              | 332                 | –                                   | 216                | –38                | 1.4 <sup>12</sup>             | 1/50                        |
| Diethylcarbonate                              | 0.98             | 4.07                     | 25                              | –                   | –                                   | 126                | –43                | insol.                        | 10/24                       |
| Diethyl cellosolve                            | 0.8              | 6.56                     | 35oc                            | 207                 | –                                   | 121                | –74                | –                             | 9.4                         |
| Diethylene glycol                             | 1.12             | 3.66                     | 124                             | 229                 | 2–                                  | 245                | –8                 | sol.                          | 1/92                        |
| Diethylene glycol-monoethyl ether             | 1.11             | 4.6                      | 96                              | 204                 | 1.2–                                | 202                | –10                | ∞                             | –                           |
| Diethylenetriamine                            | 0.95             | 3.5                      | 102                             | 399                 | –                                   | 207                | –39                | ∞                             | –                           |
| Diethyl ether, see Ethyl ether                |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Diethyl ethyl phosphonate                     | 1.03             | 5.7                      | 105                             | –                   | –                                   | 83 at 11 mm        | –                  | sl. sol.                      | –                           |
| Diethyl ketone                                | 0.82             | 2.96                     | 13                              | 452                 | –                                   | 101                | –42                | 4.7 <sup>20</sup>             | –                           |
| Diethyl malonate                              | 1.06             | 5.5                      | 93                              | –                   | –                                   | 199                | –50                | 2.1 <sup>20</sup>             | 1/40                        |
| o-Diethyl phthalate                           | 1.1              | 7.7                      | 163                             | –                   | –                                   | 302                | –40                | insol.                        | –                           |
| p-Diethyl phthalate                           | 1.1              | 7.7                      | 117                             | –                   | –                                   | 296                | –5                 | insol.                        | –                           |

|                                                                           |      |      |            |                                                           |                       |         |      |                    |         |
|---------------------------------------------------------------------------|------|------|------------|-----------------------------------------------------------|-----------------------|---------|------|--------------------|---------|
| Diethyl sulphate                                                          | 1.18 | 5.3  | 104        | 436                                                       | –                     | 208dec. | –25  | insol.             | 1/47    |
| Diglycol, <i>see</i> Diethylene glycol                                    |      |      |            |                                                           |                       |         |      |                    |         |
| 3,4-Dihydro-2H-pyran                                                      | 0.92 | 2.9  | –18        | –                                                         | –                     | 86      | –    | sol.               | –       |
| Diisobutyl ketone                                                         | 0.81 | 4.9  | 60         | –                                                         | 0.8–6.2               | 168     | –    | insol.             | –       |
| Diisobutyl carbinol                                                       | 0.8  | 5    | 74         | –                                                         | 0.8–6.1<br>(at 100 C) | 173     | –65  | –                  | 0.3/20  |
| Diisopropyl amine                                                         | 0.72 | 3.5  | –1         | –                                                         | –84                   | 83      | –61  | sl. sol.           | –       |
| Diisopropyl ether                                                         | 0.72 | 3.5  | –28        | 443                                                       | 1.4–7.9               | 69      | –86  | sl. sol.           | 150/25  |
| Diisopropyl benzene                                                       | 0.9  | 5.6  | 76oc       | 449                                                       | –                     | 205     | <–55 | –                  | –       |
| 3,3'-Dimethoxybenzidine                                                   | –    | 8.5  | 206        | –                                                         | –                     | –       | 137  | insol.             | –       |
| Dimethoxyethane                                                           | 0.85 | 3.1  | 40         | –                                                         | –                     | 65      | –113 | sol.               | –       |
| Dimethoxymethane                                                          | 0.86 | 2.63 | –18        | 237                                                       | –                     | 46      | –105 | 33                 | 330/20  |
| Dimethoxypropane                                                          | 0.85 | 3.6  | –7         | –                                                         | –                     | 95      | –    | –                  | –       |
| <i>N,N</i> -Dimethyl acetamide                                            | 0.94 | 3.0  | 77         | 354                                                       | 1.8–13.8              | 165     | –20  | ∞                  | 1.3/25  |
| Dimethylamine                                                             | 0.68 | 1.65 | –50 (<–18) | 402 (430)                                                 | 2.8–14.4              | 7.4     | –92  | v. sol.            | –       |
| <i>N,N</i> -Dimethylaniline                                               | 0.95 | 4.17 | 63         | 371                                                       | –                     | 193     | 2.5  | sl. sol.           | 1/30    |
| 2,2-Dimethyl butane                                                       | 0.65 | 3.00 | –48        | 425                                                       | 1.2–7.0               | 50      | –98  | insol.             | 400/31  |
| 2,3-Dimethyl butane                                                       | 0.7  | 3.0  | –29        | 420                                                       | 1.2–7                 | 58      | –135 | –                  | 400/39  |
| Dimethyl carbonate                                                        | 1.1  | 3.1  | 19         | –                                                         | –                     | 90      | 0.5  | insol.             | –       |
| Dimethyl chloroacetal                                                     | 1.1  | 4.3  | 43         | 232                                                       | –                     | 130     | –    | –                  | –       |
| Dimethyl ether, <i>see</i> Methyl ether                                   |      |      |            |                                                           |                       |         |      |                    |         |
| Dimethylformamide                                                         | 0.94 | 2.51 | 58         | 445                                                       | 2.2–15.2              | 153     | –61  | ∞                  | 3.7/25  |
| 1,1-Dimethylhydrazine, <i>see</i><br>Unsymmetrical dimethyl-<br>hydrazine |      |      |            |                                                           |                       |         |      |                    |         |
| 2,6-Dimethyl-4-heptanone, <i>see</i><br>Diisobutyl ketone                 |      |      |            |                                                           |                       |         |      |                    |         |
| 2,3-Dimethyl pentane                                                      | 0.69 | 3.5  | <–7        | 337                                                       | 1–7                   | 90      | –135 | –                  | 40/14   |
| Dimethyl phthalate                                                        | 1.19 | 6.7  | 146        | 556                                                       | –                     | 288     | –    | insol.             | 1/10    |
| 2,2-Dimethyl propane                                                      | 0.61 | 2.48 | <–7        | 450                                                       | 1.4–7.5               | 9.5     | –18  | insol.             | 100/21  |
| Dimethyl sulphate                                                         | 1.33 | 4.35 | 83         | 188                                                       | –                     | 189dec. | –31  | sol.               | –       |
| Dimethyl sulphide                                                         | 0.8  | 2.1  | <–18       | 206                                                       | 2.2–19.7              | 37      | –83  | insol.             | –       |
| Dimethyl sulphoxide                                                       | 1.01 | –    | 95         | 215oc                                                     | 2.6–28.5              | 189     | 18   | sol.               | 0.4/20  |
| 2,4-Dinitroaniline                                                        | 1.62 | 6.3  | 244        | –                                                         | –                     | –       | 188  | insol.             | –       |
| <i>m</i> -Dinitrobenzene                                                  | 1.58 | –    | 150        | severe explosion hazard when<br>exposed to shock or flame |                       | 291     | 90   | 0.3 <sup>99</sup>  | –       |
| <i>o</i> -Dinitrobenzene                                                  | 1.31 | 5.8  | 150        |                                                           |                       | 319     | 118  | sl. sol.           | –       |
| <i>p</i> -Dinitrobenzene                                                  | 1.63 | –    | 150        | –                                                         | –                     | 299     | 172  | 0.18 <sup>38</sup> | –       |
| 2,4-Dinitrotoluene                                                        | 1.4  | 6.3  | 207        | –                                                         | –                     | 300     | 70   | 0.03 <sup>20</sup> | –       |
| Di- <i>n</i> -Octyl phthalate                                             | 0.97 | 14.4 | 219        | –                                                         | –                     | 385     | –30  | –                  | –       |
| Di-sec-Octyl phthalate                                                    | 0.99 | 16   | 218        | 410                                                       | –                     | 358     | –55  | –                  | 1.2/200 |
| 1,4-Dioxane                                                               | 1.04 | 3.0  | 12         | 180                                                       | 2–22.2                | 101     | 10   | ∞                  | 40/25   |
| Dipentene                                                                 | 0.85 | 4.66 | 45         | 237                                                       | 0.7–6.1               | 178     | –97  | insol.             | 1/14    |
| Dipentene, dioxide <i>see p</i> -Mentha-<br>1,8-diene                     |      |      |            |                                                           |                       |         |      |                    |         |
| Dipentene monoxide                                                        | 0.93 | 4.45 | 67         | –                                                         | –                     | 75      | <–6  | –                  | –       |

Table 6.1 Cont'd

| <i>Substance</i>                                     | <i>Specific gravity</i> | <i>Vapour density</i><br>(air = 1) | <i>Flash point</i> <sup>(1)</sup><br>( °C) | <i>Ignition temp.</i><br>( °C) | <i>Flammable limits</i> <sup>(1)</sup><br>(%) | <i>Boiling point</i><br>( °C) | <i>Melting point</i><br>( °C) | <i>Solubility in water</i><br>(g/100 g) | <i>Vapour pressure</i><br>(mm Hg/ °C) |
|------------------------------------------------------|-------------------------|------------------------------------|--------------------------------------------|--------------------------------|-----------------------------------------------|-------------------------------|-------------------------------|-----------------------------------------|---------------------------------------|
| Diphenylamine                                        | 1.16                    | 5.8                                | 153                                        | 634                            | –                                             | 302                           | 53                            | insol.                                  | 1/108                                 |
| Diphenylmethane                                      | 1.01                    | 5.8                                | 130                                        | 486                            | –                                             | 266                           | 26                            | insol.                                  | 1/76                                  |
| Dipropylene glycol methyl ether                      | 0.95                    | 5.1                                | 85                                         | –                              | –                                             | 189                           | –                             | –                                       | –                                     |
| <i>n</i> -Dodecane                                   | 0.75                    | 5.96                               | 74                                         | 204                            | 0.6–                                          | 216                           | –12                           | insol.                                  | 1/48                                  |
| Epichlorohydrin                                      | 1.18                    | 3.29                               | 41                                         | –                              | –                                             | 117                           | –48                           | <5                                      | 10/17                                 |
| 1,2-Epoxy-propane                                    | 0.83                    | 2.0                                | –37                                        | –                              | 2.1–21.5                                      | 34                            | –104                          | v. sol.                                 | 400/18                                |
| Ethane                                               | 0.57                    | 1.04                               | –                                          | 515                            | 3–12.5                                        | –89                           | –183                          | insol.                                  | –                                     |
| Ethanediol, <i>see</i> Ethylene glycol               |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethanethiol                                          | 0.84                    | 2.14                               | <27                                        | 299                            | 2.8–18                                        | 37                            | –144                          | 1.5                                     | –                                     |
| Ethanoic acid, <i>see</i> Acetic acid                |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethanol                                              | 0.79                    | 1.59                               | 12                                         | 423                            | 3.3–19                                        | 79                            | –114                          | ∞                                       | 40/19                                 |
| Ethanolamine                                         | 1.02                    | 2.11                               | 85                                         | –                              | –                                             | 170                           | 11                            | ∞                                       | 6/60                                  |
| Ethoxy acetylene                                     | 0.79                    | 2.4                                | <–7                                        | 100exp.                        | –                                             | 50                            | –                             | insol.                                  | –                                     |
| 2-Ethoxy ethanol, <i>see</i> Cellosolve              |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| 2-Ethoxy ethylacetate, <i>see</i> Cellosolve acetate |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethyl acetanilide                                    | 0.94                    | 5.62                               | 52                                         | –                              | –                                             | 258                           | 54                            | insol.                                  | –                                     |
| Ethyl acetate                                        | 0.90                    | 3.04                               | –4.4                                       | 427                            | 2.18–11.5                                     | 77                            | –84                           | 7.5 <sup>20</sup>                       | 100/27                                |
| Ethyl acetoacetate                                   | 1.03                    | 4.48                               | 84                                         | –                              | –                                             | 181                           | –45                           | 13 <sup>17</sup>                        | 1/29                                  |
| Ethyl acrylate                                       | 0.92                    | 3.5                                | 16                                         | 273                            | 1.8–                                          | 100                           | <–72                          | sol.                                    | 29/20                                 |
| Ethyl alcohol, <i>see</i> Ethanol                    |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethyl aldehyde, <i>see</i> Acetaldehyde              |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethylamine                                           | 0.80                    | 1.56                               | <–18                                       | 384                            | 3.5–14                                        | 17                            | –81                           | ∞                                       | 400/2                                 |
| Ethyl amyl ketone                                    | 0.85                    | –                                  | 57                                         | –                              | –                                             | 161                           | –                             | insol.                                  | –                                     |
| <i>n</i> -Ethyl aniline                              | 0.96                    | 4.18                               | 85                                         | –                              | –                                             | 205                           | –64                           | insol.                                  | 1/38                                  |
| Ethyl benzene                                        | 0.9                     | 3.7                                | 15                                         | 432                            | 1–6.7                                         | 136                           | –95                           | 0.01 <sup>15</sup>                      | 10/26                                 |
| Ethyl benzoate                                       | 1.15                    | 5.17                               | >96                                        | –                              | –                                             | 213                           | –35                           | insol.                                  | 1/40                                  |
| Ethyl bromide, <i>see</i> Bromoethane                |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethyl bromoacetate                                   | 1.51                    | 5.8                                | 48                                         | –                              | –                                             | 159                           | <–20                          | insol.                                  | –                                     |
| Ethyl butyl ketone                                   | 0.82                    | 3.93                               | 46                                         | –                              | –                                             | 148                           | –37                           | insol.                                  | –                                     |
| 2-Ethyl butyraldehyde                                | 0.8                     | 3.5                                | 21oc                                       | –                              | 1–8                                           | 117                           | –90                           | –                                       | 14/20                                 |
| Ethyl butyrate                                       | 0.88                    | 4.0                                | 26                                         | 463                            | –                                             | 121                           | –97                           | 0.68 <sup>25</sup>                      | 10/15                                 |
| Ethyl chloride                                       | 0.92                    | 2.2                                | –50                                        | 519                            | 3.6–15.4                                      | 12                            | –139                          | 0.45                                    | 1000/20                               |
| Ethyl chloroacetate                                  | 1.26                    | 4.3                                | 66                                         | –                              | –                                             | 144                           | –27                           | insol.                                  | 10/38                                 |
| Ethyl chloroformate                                  | 1.36                    | 3.74                               | 16                                         | –                              | –                                             | 95                            | –81                           | dec.                                    | –                                     |
| Ethyl crotonate                                      | 0.92                    | 3.93                               | 2                                          | –                              | –                                             | 143–7                         | 45                            | insol.                                  | –                                     |
| Ethyl cyanoacetate                                   | 1.06                    | 3.9                                | 110                                        | –                              | –                                             | 206                           | –23                           | 2 <sup>25</sup>                         | 1/68                                  |
| Ethyl cyanide, <i>see</i> Propionitrile              |                         |                                    |                                            |                                |                                               |                               |                               |                                         |                                       |
| Ethylene                                             | 0.001                   | 1.0                                | –                                          | 450                            | 3.1–32                                        | –104                          | –169                          | 26 <sup>0</sup>                         | –                                     |

|                                                            |      |         |       |              |          |         |          |                   |         |
|------------------------------------------------------------|------|---------|-------|--------------|----------|---------|----------|-------------------|---------|
| Ethylene chlorohydrin                                      | 1.21 | 2.78    | 60oc  | 425          | 4.9–15.9 | 128     | –69      | ∞                 | 10/30   |
| Ethylene diamine                                           | 0.90 | 2.07    | 43    | –            | –        | 117     | 8.5      | v. sol.           | 11/20   |
| Ethylene dichloride                                        | 1.26 | 3.4     | 13    | 413          | 6.2–15.9 | 83      | –36      | sl. sol.          | 100/29  |
| Ethylene glycol                                            | 1.11 | 2.14    | 111   | 413          | 3.2–     | 198     | –13      | ∞                 | 0.05/20 |
| Ethylene glycol monobutyl ether,<br>see Butyl cellosolve   |      |         |       |              |          |         |          |                   |         |
| Ethylene glycol monoethyl ether,<br>see Cellosolve         |      |         |       |              |          |         |          |                   |         |
| Ethylene glycol monomethyl<br>ether, see Methyl cellosolve |      |         |       |              |          |         |          |                   |         |
| Ethylenimine, see Aziridine                                |      |         |       |              |          |         |          |                   |         |
| Ethylene oxide                                             | 0.87 | 1.49    | <–18  | 429          | 3–100    | 11      | –111     | sol.              | 1095/20 |
| Ethyl ether                                                | 0.71 | 2.55    | –45   | 180          | 1.85–48  | 34      | –123     | 7.5 <sup>20</sup> | 442/20  |
| Ethyl ethynyl ether, see<br>Ethoxyacetylene                |      |         |       |              |          |         |          |                   |         |
| Ethyl formate                                              | 0.95 | 2.55    | –20   | 455          | 2.7–13.5 | 54      | –79      | 11 <sup>18</sup>  | 100/5   |
| 2-Ethyl hexanol                                            | 0.83 | 4.49    | 84    | –            | –        | 180–5   | <–76     | insol.            | 0.2/20  |
| Ethyl lactate                                              | 1.04 | 4.07    | 46    | 400          | 1.5–30   | 154     | –        | ∞                 | –       |
| Ethyl malonate, see Diethyl<br>malonate                    |      |         |       |              |          |         |          |                   |         |
| Ethyl mercaptan, see Ethanethiol                           |      |         |       |              |          |         |          |                   |         |
| Ethyl methyl ether                                         | 0.7  | 2.1     | –37   | 190          | 2–10     | 11      | –        | –                 | –       |
| N-Ethylmorpholine                                          | 0.92 | 4.00    | 32    | –            | –        | 138     | –        | ∞                 | –       |
| Ethyl nitrite                                              | 0.90 | 2.59    | –35   | 90(explodes) | 4.1–50   | 17      | –        | dec.              | –       |
| Ethyl oxalate                                              | 1.08 | 5.04    | 76    | –            | –        | 186     | –41      | sl. sol.          | –       |
| Ethyl propionate                                           | 0.9  | 3.5     | 12    | 477          | 2–11     | 99      | –73      | –                 | 40/27   |
| 2-Ethyl-3-propyl acrolein                                  | 0.85 | 4.35    | 68oc  | –            | –        | 175     | <100     | insol.            | 1/20    |
| Ethyl silicate                                             | 0.93 | 7.22    | 52    | –            | –        | 165     | 110subl. | dec.              | 1/20    |
| Ethyl vinyl ether                                          | 0.75 | 2.46    | <–46  | 202          | 1.7–28   | 36      | –115     | sl. sol.          | –       |
| Fluoroethylene                                             | –    | –       | –     | –            | 2.6–21.7 | –51     | –160     | insol.            | –       |
| Formaldehyde                                               | 0.82 | 1.08    | –     | 430          | 7.0–73   | –19     | –92      | sol.              | –       |
| Formalin (39% formaldehyde<br>methanol free)               | 0.82 | –       | 85    | –            | –        | 101     | –        | –                 | –       |
| Formalin (37% formaldehyde-<br>15% methanol)               | –    | –       | 50    | –            | –        | 101     | –        | –                 | –       |
| Formamide                                                  | 1.13 | –       | 155oc | –            | –        | 211dec. | 2.6      | ∞                 | 30/129  |
| Form-dimethylamide, see<br>Dimethylformamide               |      |         |       |              |          |         |          |                   |         |
| Formic acid                                                | 1.22 | 1.59    | 69oc  | 601          | 18–57    | 101     | 8.2      | ∞                 | 40/24   |
| Furan                                                      | 0.94 | 2.35    | <0    | –            | 2–14     | 32      | –86      | insol             | –       |
| Furfural                                                   | 1.16 | 3.31    | 60    | 316          | 2.1–     | 162     | –37      | 9.1 <sup>13</sup> | –       |
| Furfuryl alcohol                                           | 1.13 | 3.37    | 75    | 491<br>(916) | 1.8–16.3 | 171     | –31      | ∞                 | 1/32    |
| Gasoline (petrol)                                          | 0.8  | 3.0–4.0 | –43   | 280–456      | 1.4–7.6  | 38–204  | –        | –                 | –       |
| Glycerol                                                   | 1.26 | 3.17    | 160   | 354          | –        | 290dec. | 18       | ∞                 | 1.26/20 |

Table 6.1 Cont'd

| Substance                            | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C)     | Ignition temp. (°C)           | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/°C) |
|--------------------------------------|------------------|--------------------------|-------------------------------------|-------------------------------|-------------------------------------|--------------------|--------------------|-------------------------------|----------------------------|
| Heptane                              | 0.68             | 3.45                     | −4                                  | 223                           | 1.2–6.7                             | 98                 | −91                | insol.                        | 40/22                      |
| 2-Heptanone, see Methyl amyl ketone  |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| 3-Heptanone, see Ethyl butyl ketone  |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| <i>n</i> -Heptylamine                | 0.77             | 4.0                      | 54oc                                | –                             | –                                   | 158                | −23                | sl. sol.                      | –                          |
| Hexachlorobenzene                    | 1.57             | 9.8                      | 242                                 | –                             | –                                   | 322                | 230                | insol.                        | –                          |
| 2,4-Hexadienal                       | 0.9              | –                        | 68oc                                | –                             | 1–8                                 | 170                | –                  | sl. sol.                      | –                          |
| 1,4-Hexadiene                        | 0.7              | 2.8                      | −21                                 |                               | 2–6                                 | 64                 | –                  | insol.                        | –                          |
| Hexane                               | 0.66             | 2.97                     | −22                                 | 261                           | 1.1–7.5                             | 68                 | −96                | insol.                        | 100/16                     |
| Hexanedioic acid, see Adipic acid    |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| Hexanoic acid, see Caproic acid      |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| <i>n</i> -Hexanol                    | 0.81             | 3.52                     | 60                                  | 293                           | –                                   | 158                | −45                | sl. sol.                      | 1/24                       |
| 2-Hexanone, see Methyl butyl ketone  |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| 1-Hexene                             | 0.7              | 2.97                     | <−7                                 | –                             | 1.2–6.9                             | 63                 | −139               | insol.                        | 310/38                     |
| 2-Hexene                             | 0.68             | 2.92                     | <−7                                 | –                             | –                                   | 69                 | −146               | insol.                        | –                          |
| Hexone, see iso-Butyl methyl ketone  |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| sec-Hexyl acetate                    | 0.86             | 4.97                     | 45                                  | –                             | –                                   | 141                | −64                | insol.                        | 4/20                       |
| Hexyl alcohol, see <i>n</i> -Hexanol |                  |                          |                                     |                               |                                     |                    |                    |                               |                            |
| Hexyl amine                          | 0.76             | 3.49                     | 29oc                                | –                             | –                                   | 129                | −19                | sl. sol.                      | –                          |
| Hydracrylic acid-β-lactone           | 1.15             | 2.5                      | 74                                  | –                             | 2.9–                                | 155                | −33                | dec.                          | –                          |
| Hydrazine                            | 1.0              | 1.1                      | 38                                  | Varies with surface<br>23–264 | 4.7–100                             | 113                | 1.4                | v. sol.                       | 14.4/25                    |
| Hydrocyanic acid                     | 0.69             | 0.93                     | −18                                 | 538                           | 6–41                                | 26                 | −14                | ∞                             | 400/10                     |
| Hydrogen                             | 0.09             | 0.069                    | –                                   | 585                           | 4–75                                | −253               | −259               | 2.1                           | –                          |
| Hydrogen sulphide                    | 1.5              | 1.2                      | –                                   | 260                           | 4.3–46                              | −60                | −83                | 437                           | 20 atm/25                  |
| <i>p</i> -Hydroquinone               | 1.33             | 3.8                      | 165                                 | 515                           | –                                   | 285                | 171                | sol.                          | 4/150                      |
| Hydroquinone monomethyl ether        | 1.55             | –                        | 131                                 | 421                           | –                                   | 246                | 54                 | sol.                          | –                          |
| Hydroxylamine                        | 1.20             | –                        | 129exp.                             | –                             | –                                   | 56                 | 34                 | sol.                          | –                          |
| Isoprene                             | 0.68             | 2.35                     | −54                                 | 220                           | –                                   | 34                 | −147               | insol.                        | –                          |
| Kerosene                             | 0.81             | 4.5                      | 38                                  | 229                           | 0.7–5                               | 170–300            | <−46               | –                             | –                          |
|                                      |                  |                          | dependent upon<br>specific fraction |                               |                                     |                    |                    |                               |                            |
| Lactonitrile                         | 0.99             | 2.45                     | 77                                  | –                             | –                                   | 182dec.            | −40                | ∞                             | –                          |
| Linseed oil                          | 0.9              | –                        | 22                                  | 343                           | –                                   | –                  | −19                | –                             | –                          |
| Maleic anhydride                     | 0.9              | 3.4                      | 102                                 | 477                           | 1.4–7.1                             | 202                | 58                 | dec.                          | 1/44                       |



|                                                                      |      |      |      |     |           |      |      |          |         |
|----------------------------------------------------------------------|------|------|------|-----|-----------|------|------|----------|---------|
| <i>p</i> -Mentha-1,8-diene                                           | 3.84 | 7.4  | 45   | 237 | 0.7–6.1   | 170  | <60  | insol.   | –       |
| 2-Mercaptoethanol                                                    | 1.14 | 2.69 | 74oc | –   | –         | 157  | –    | sol.     | 1/20    |
| Mesityl oxide                                                        | 0.86 | 3.5  | 31   | 344 | –         | 130  | –59  | sol.     | 10/26   |
| $\alpha$ -Methacrylic acid                                           | 1.02 | –    | 77oc | –   | –         | 158  | 16   | sol.     | 1/25    |
| Methane                                                              | 0.42 | 0.6  | –    | 537 | 5–15      | –161 | –183 | sl. sol. | –       |
| 3-(3-Methoxypropoxy)-1-propanol, see Dipropylene glycol methyl ether |      |      |      |     |           |      |      |          |         |
| Methyl acetate                                                       | 0.97 | 2.55 | –9   | 502 | 3.1–16    | 57   | –99  | v. sol.  | 100/9.4 |
| Methyl acetylene, see Propyne                                        |      |      |      |     |           |      |      |          |         |
| Methyl acrylate                                                      | 0.95 | 3.0  | –3oc | –   | 2.8–25    | 80   | –75  | sl. sol. | 100/28  |
| Methylal, see Dimethoxymethane                                       |      |      |      |     |           |      |      |          |         |
| Methyl alcohol                                                       | 0.79 | 1.11 | 12   | 464 | 6–36.5    | 65   | –98  | $\infty$ | 100/21  |
| Methyl amyl alcohol                                                  | 0.80 | 3.5  | 41   | –   | 1–5.5     | 130  | <–90 | sl. sol. | 3/20    |
| Methyl- <i>n</i> -amyl ketone                                        | 0.81 | 3.9  | 49oc | 533 | –         | 151  | –35  | sl. sol. | 3/20    |
| Methyl bromide                                                       | 1.73 | 3.27 | –    | 537 | 10–16     | 4    | –95  | insol.   | –       |
| 2-Methyl-1-butene                                                    | 0.66 | 2.4  | <–7  | –   | –         | 39   | –134 | insol.   | –       |
| 2-Methyl-2-butene                                                    | 0.67 | 2.4  | <–17 | –   | –         | 38   | –123 | sl. sol. | –       |
| 3-Methyl-1-butene                                                    | 0.67 | 2.42 | <–57 | 365 | 1.5–9.1   | 20   | –168 | insol.   | –       |
| <i>N</i> -Methylbutylamine                                           | 0.74 | 3.0  | 13oc | –   | –         | 91   | –    | sol.     | –       |
| Methyl butyl ketone                                                  | 0.81 | 3.45 | 35oc | 533 | 1.2–8     | 126  | –57  | –        | 10/39   |
| Methyl butyrate                                                      | 0.90 | 3.53 | 14   | –   | –         | 102  | <–97 | sl. sol. | 40/30   |
| Methyl cellosolve                                                    | 0.97 | 2.62 | 46oc | 288 | 2.5–14    | 125  | –87  | $\infty$ | 6/20    |
| Methyl cellosolve acetate                                            | 1.01 | 4.07 | 56   | 394 | 1.7–8.2   | 145  | –70  | sol.     | –       |
| Methyl chloride                                                      | 0.98 | 1.8  | <0oc | 632 | 10.7–17.4 | –24  | –98  | sl. sol. | –       |
| Methyl chloroform, see 1,1,1-Trichloroethane                         |      |      |      |     |           |      |      |          |         |
| Methyl chloroformate                                                 | 1.24 | 3.26 | 12   | 504 | –         | 73   | –    | dec.     | –       |
| Methyl cyanide, see Acetonitrile                                     |      |      |      |     |           |      |      |          |         |
| Methyl cyclohexane                                                   | 0.77 | 3.39 | –4   | 285 | 1.2–      | 100  | –126 | insol.   | 40/22   |
| $\sigma$ -Methyl cyclohexanol                                        | 0.92 | 3.93 | 68   | 296 | –         | 165  | –20  | sl. sol. | –       |
| 2-Methyl cyclohexanone                                               | 0.92 | 3.86 | 48   | –   | –         | 165  | –    | insol.   | –       |
| 4-Methyl cyclohexene                                                 | 0.80 | 3.34 | –1oc | –   | –         | 103  | –116 | insol.   | 10/38   |
| Methylene chlorobromide, see Bromochloromethane                      |      |      |      |     |           |      |      |          |         |
| Methyl ether                                                         | 0.66 | 1.56 | –41  | 350 | 3.4–18    | –24  | –139 | sol.     | –       |
| Methyl ethyl ether                                                   | 0.73 | 2.07 | –37  | 190 | 2–10.1    | 11   | –    | sol.     | –       |
| Methyl ethyl ketone                                                  | 0.81 | 2.5  | –7   | 515 | 2–10      | 80   | –87  | v. sol.  | –       |
| Methyl formate                                                       | 0.99 | 2.1  | –19  | 456 | 5.9–20    | 32   | –100 | v. sol.  | 400/16  |
| 2-Methyl furan                                                       | 0.92 | 2.8  | –30  | –   | –         | 63   | –89  | insol.   | 139/20  |
| 5-Methyl-3-heptanone, see Ethyl amyl ketone                          |      |      |      |     |           |      |      |          |         |
| Methyl hydrazine                                                     | 0.9  | 1.6  | <27  | –   | –         | 87   | <–80 | sol.     | –       |
| Methyl isobutyl ketone                                               | 0.80 | 3.5  | 23   | 460 | 1.4–7.5   | 117  | –85  | sl. sol. | 16/20   |

Table 6.1 Cont'd

| Substance                                              | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|--------------------------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| Methyl isobutyrate                                     | 0.86             | 3.5                      | 13oc                            | 482                 | –                                   | 92                 | –84                | sl. sol.                      | –                           |
| Methyl mercaptan                                       | 0.87             | 1.66                     | <–18                            | –                   | 3.9–21.8                            | 7.6                | –123               | sl. sol.                      | –                           |
| Methyl methacrylate                                    | 0.94             | 3.6                      | 10                              | 421                 | 2.1–12.5                            | 100                | –50                | sl. sol.                      | 40/25                       |
| 1-Methylnaphthalene                                    | 1.03             | –                        | –                               | 528                 | –                                   | 240–3              | –22                | insol.                        | –                           |
| 2-Methyl-2-propanethiol, see <i>t</i> -Butyl mercaptan |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Methyl- <i>n</i> -Propyl ketone                        | 0.81             | 3.0                      | 7                               | 505                 | 1.6–8.2                             | 102                | –78                | sl. sol.                      | –                           |
| 1-Methylpyrrole                                        | 0.91             | 2.8                      | 16                              | –                   | –                                   | 115                | –57                | insol.                        | –                           |
| Methyl salicylate                                      | 1.18             | 5.24                     | 101                             | 454                 | –                                   | 223                | –8.3               | sl. sol.                      | 1/54                        |
| <i>a</i> -Methyl styrene                               | 0.92             | 4.08                     | 54                              | 574                 | 1.9–6.1                             | 167–70             | –23                | insol.                        | –                           |
| <i>m</i> , <i>p</i> -Methyl styrene                    | 0.89             | 4.08                     | 57                              | 494                 | 0.9                                 | 170                | –83                | –                             | –                           |
| Methyl sulphate, see Dimethyl sulphate                 |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Methyl sulphide, see Dimethyl sulphide                 |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Methyl vinyl ether                                     | 0.77             | 2.0                      | –51                             | –                   | –                                   | 8                  | –122               | sl. sol.                      | 1052/20                     |
| Mixed acids                                            | –                | –                        | None                            | –                   | None                                | Varies             | Varies             | –                             | –                           |
| Monomethylamine                                        | –                | 1.1                      | –10                             | 430                 | 4.9–20.8                            | –6.3               | –94                | v. sol                        | –                           |
| Morpholine                                             | 0.99             | 3.00                     | 38oc                            | 310                 | –                                   | 128                | –4.9               | ∞                             | –                           |
| Naphtha (coal tar)                                     | 0.87             | –                        | 42                              | 277                 | –                                   | 149–216            | –                  | –                             | –                           |
| Naphtha (petroleum), see Petroleum ether               |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Naphtha, varnish makers and painters, 50 flash         | <1               | 4.1                      | 10                              | 232                 | 0.9–6.7                             | 116–43             | –                  | –                             | –                           |
| Naphtha, varnish makers and painters, high flash       | <1               | 4.3                      | 29                              | 232                 | 1–6                                 | 139–77             | –                  | –                             | –                           |
| Naphtha, varnish makers and painters, regular          | <1               | –                        | –2                              | 232                 | 0.9–6                               | 100–60             | –                  | –                             | –                           |
| Naphthalene                                            | 1.15             | 4.42                     | 79                              | 526                 | 0.9–5.9                             | 210                | 80                 | insol.                        | –                           |
| 2-Naphthol                                             | 1.22             | 4.97                     | 153                             | –                   | –                                   | 295                | 123                | insol.                        | 10/45                       |
| 1-Naphthylamine                                        | 1.12             | 4.93                     | 157                             | –                   | –                                   | 301                | 50                 | sl. sol.                      | –                           |
| Natural gas                                            | –                | –                        | –                               | 482                 | 3.8–17                              | –                  | –                  | –                             | –                           |
| Nickel carbonyl                                        | 1.32             | ~6                       | –                               | 60exp.              | 2–                                  | 43                 | –25                | sl. sol.                      | 400/26                      |
| Nicotine                                               | 1.01             | 5.61                     | –                               | 244                 | 0.7–4.0                             | 247                | <–80               | ∞                             | 1/62                        |
| <i>o</i> -Nitroaniline                                 | 1.44             | –                        | 168oc                           | 521                 | –                                   | 284                | 71                 | sl. sol.                      | 1/104                       |
| <i>p</i> -Nitroaniline                                 | 1.44             | –                        | 199                             | –                   | –                                   | 336                | 146                | insol.                        | 1/124                       |
| Nitrobenzene                                           | 1.20             | 4.24                     | 88                              | 482                 | 1.8–                                | 211                | 5                  | sl. sol.                      | 1/44                        |
|                                                        |                  |                          |                                 |                     | at 93 °C                            |                    |                    |                               |                             |
| <i>o</i> -Nitrobiphenyl                                | 1.44             | 6.9                      | 143                             | 180                 | –                                   | 330                | 35                 | insol.                        | 2/140                       |

|                                                        |      |      |        |         |          |         |         |          |          |
|--------------------------------------------------------|------|------|--------|---------|----------|---------|---------|----------|----------|
| Nitroethane                                            | 1.05 | 2.58 | 38     | 360–415 | 3.4–     | 114     | –90     | sol.     | 16/20    |
| Nitromethane                                           | 1.14 | 2.11 | 35     | 418     | 7.3–     | 101     | –28     | sol.     | 28/20    |
| α-Nitronaphthalene                                     | 1.14 | 5.96 | 164    | –       | –        | 304     | 60      | insol.   | –        |
| 1-Nitropropane                                         | 0.99 | 3.06 | 49oc   | 421     | 2.6–     | 131     | –108    | sl. sol. | 8/20     |
| 2-Nitropropane                                         | 0.99 | 3.06 | 39oc   | 428     | 2.6–     | 120     | –93     | sl. sol. | 10/16    |
| <i>m</i> -Nitrotoluene                                 | 1.15 | 4.7  | 106    | –       | –        | 232     | 15      | insol.   | 1/50     |
| <i>o</i> -Nitrotoluene                                 | 1.16 | 4.72 | 106    | –       | –        | 220     | –4.1    | insol.   | 1/50     |
| <i>p</i> -Nitrotoluene                                 | 1.29 | 4.72 | 106    | –       | –        | 238     | 52      | insol.   | 1/54     |
| Nonyl phenol                                           | 0.95 | 7.6  | 141    | –       | –        | 290–301 | –       | –        | –        |
| Octane                                                 | 0.70 | 3.86 | 13     | 220     | 1.0–4.66 | 125     | –57     | insol.   | 10/19    |
| Octanoic acid                                          | 0.91 | 5.0  | 132oc  | –       | –        | 240     | 16      | sl. sol. | –        |
| 1-Octanol                                              | 0.83 | 4.5  | 81     | –       | –        | 194     | –17     | sol.     | –        |
| 2-Octanol                                              | 0.82 | 4.48 | 88     | –       | –        | 178     | –39     | sl. sol. | –        |
| Oil, lubricating                                       | –    | –    | >149oc | 260–371 | –        | 360     | <–46    | –        | –        |
| Oil, mineral oil mist                                  | 0.81 | –    | 193oc  | –       | –        | 360     | –       | –        | –        |
| Oil, olive                                             | 0.9  | –    | 225    | 343     | –        | –       | –6      | –        | –        |
| Oil, peanut                                            | 0.9  | –    | 282    | 470     | –        | –       | 3       | –        | –        |
| Oil, soybean                                           | 0.9  | –    | 282    | 445     | –        | –       | 22      | –        | –        |
| Oil, vegetable                                         | <1   | –    | 321    | –       | –        | –       | –9–1    | –        | –        |
| Oleic acid                                             | 0.89 | –    | 189    | 363     | –        | 360     | 14      | insol.   | 1/77     |
| Paraffin wax                                           | 0.9  | –    | 199    | 245     | –        | >370    | 42–60   | –        | –        |
| Paraformaldehyde                                       | 1.39 | –    | 70     | 300     | –        | –       | 120–170 | –        | 145/25   |
| Paraldehyde                                            | 0.99 | 4.55 | 36oc   | 238     | 1.3–     | 128     | 12      | v. sol.  | –        |
| Pentaborane                                            | 0.66 | 2.2  | 30     | –       | 0.4–     | 58      | –47     | dec.     | 66/0     |
| <i>n</i> -Pentane                                      | 0.63 | 2.48 | –49    | 309     | 1.4–8    | 36      | –130    | v. sol.  | 400/19   |
| iso-Pentane                                            | 0.62 | 2.48 | –51    | 420     | 1.4–7.6  | 28      | –161    | insol.   | –        |
| 1,5-Pentanediol                                        | 0.99 | 3.59 | 135    | 334     | –        | 240     | –16     | sol.     | <0.01/20 |
| 2,4-Pentanedione                                       | 0.98 | 3.45 | 41oc   | –       | –        | 136–40  | –23     | v. sol.  | –        |
| <i>n</i> -Pentanol, <i>see n</i> -Amyl alcohol         |      |      |        |         |          |         |         |          |          |
| 2-Pentanol                                             | 0.81 | 3.03 | 39     | 347     | 1.2–9.0  | 119     | –       | v. sol.  | –        |
| 2-Pentanone, <i>see</i> Methyl <i>n</i> -propyl ketone |      |      |        |         |          |         |         |          |          |
| 3-Pentanone, <i>see</i> Diethyl ketone                 |      |      |        |         |          |         |         |          |          |
| Pentene, <i>see</i> Amylene                            |      |      |        |         |          |         |         |          |          |
| <i>n</i> -Pentyl acetate, <i>see n</i> -Amyl acetate   |      |      |        |         |          |         |         |          |          |
| sec-Pentyl acetate, <i>see</i> sec-Amyl acetate        |      |      |        |         |          |         |         |          |          |
| Pentyl alcohol, <i>see n</i> -Amyl alcohol             |      |      |        |         |          |         |         |          |          |
| Pentyl amine, <i>see n</i> -Amylamine                  |      |      |        |         |          |         |         |          |          |
| iso-Pentyl nitrite, <i>see</i> Amyl nitrite            |      |      |        |         |          |         |         |          |          |
| Peracetic acid (40% acetic acid solution)              | 1.23 | –    | 41     | 110exp. | –        | 105     | –30     | v. sol.  | –        |
| Petroleum ethers                                       | 0.6  | 2.50 | <–17   | 288     | 1–6      | 30–160  | <–73    | –        | –        |

Table 6.1 Cont'd

| Substance                                        | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|--------------------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| Phenol                                           | 1.07             | 3.24                     | 79                              | 715                 | 1.5–                                | 181                | 40                 | sol.                          | –                           |
| Phenyl acetate                                   | 1.09             | 4.7                      | 80                              | –                   | –                                   | 196                | –                  | sl. sol.                      | –                           |
| Phenylcyclohexane, see Cyclohexylbenzene         |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| <i>p</i> -Phenylenediamine                       | –                | 3.7                      | 156                             | –                   | –                                   | 267                | 140                | sol.                          | –                           |
| Phenylethanolamine                               | 1.09             | –                        | 152                             | –                   | –                                   | 285                | 35                 | 4.6 <sup>20</sup>             | <0.01/20                    |
| Phenyl ether                                     | 1.09             | 5.86                     | 96oc                            | 646                 | –                                   | 258                | 27                 | insol.                        | 0.021/25                    |
| Phenyl ether – Biphenyl mixture                  | 1.06             | –                        | 124oc                           | 610                 | –                                   | 257                | 12                 | –                             | –                           |
| Phenylhydrazine                                  | 1.09             | 3.7                      | 89                              | 174                 | –                                   | 243dec.            | 20                 | sol.                          | 1/72                        |
| <i>o</i> -Phenyl phenol                          | 1.21             | –                        | 124                             | –                   | –                                   | 286                | 57                 | insol.                        | 1/100                       |
| Phorone                                          | 0.88             | 4.8                      | 85                              | –                   | –                                   | 197                | 28                 | sl. sol.                      | –                           |
| iso-Phorone                                      | 0.93             | 4.77                     | 96oc                            | 462                 | 0.8–3.8                             | 215                | –8                 | sl. sol.                      | –                           |
| Phosdrin                                         | 1.23             | –                        | 79oc                            | –                   | –                                   | 107                | –                  | –                             | –                           |
| Phosphorus (white and yellow)                    | 1.82             | 4.42                     | –                               | 30                  | spontaneous ignition in dry air     | 280                | 44                 | sl. sol.                      | 1/77                        |
| Phosphorus (red)                                 | 2.34             | 4.77                     | –                               | 260                 | –                                   | 280                | 590                | v. sol.                       | –                           |
| Phosphorus pentasulphide                         | 2.03             | –                        | –                               | 142                 | –                                   | 514                | 276                | insol.                        | –                           |
| Phosphorus tribromide                            | 2.8              | –                        | –                               | 100                 | –                                   | 173                | –40                | insol.                        | 10/48                       |
| Phthalic anhydride                               | 1.53             | 5.10                     | 151                             | 584                 | 1.7–10.4                            | 284                | 131                | sl. sol.                      | 1/97                        |
| 2-Picoline                                       | 0.95             | 3.2                      | 39oc                            | 538                 | –                                   | 129                | –70                | v. sol.                       | 10/24                       |
| 4-Picoline                                       | 0.96             | 3.21                     | 57oc                            | –                   | –                                   | 143                | 4                  | ∞                             | –                           |
| Picric acid                                      | 1.76             | 7.9                      | 150                             | 300                 | –                                   | >300exp.           | 122                | sol.                          | –                           |
| 2-Pinene                                         | 0.86             | 4.7                      | 33                              | –                   | –                                   | 156                | –55                | sl. sol.                      | 10/37                       |
| Piperidine                                       | 0.86             | 3.0                      | 16                              | –                   | –                                   | 106                | –7                 | ∞                             | 40/29                       |
| Piperylene                                       | 0.68             | 2.4                      | –43                             | –                   | 2–8.3                               | 42                 | –141               | insol.                        | –                           |
| Propane                                          | 0.58             | 1.56                     | –                               | 468                 | 2.2–9.5                             | –45                | –187               | insol.                        | –                           |
| 1,3-Propanediamine                               | 0.86             | 2.56                     | 24oc                            | –                   | –                                   | 136                | –24                | v. sol.                       | –                           |
| 1,2-Propanediol                                  | 1.04             | 2.62                     | 99                              | 371                 | 2.6–12.5                            | 189                | –59                | ∞                             | –                           |
| <i>n</i> -Propanol, see <i>n</i> -Propyl alcohol |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Propargyl alcohol                                | 0.96             | 1.93                     | 36oc                            | –                   | 3.4–                                | 115                | –17                | sol.                          | 12/20                       |
| Propargyl bromide                                | 1.56             | 4.1                      | 10                              | 324                 | 3.0–                                | 90                 | –61                | –                             | –                           |
| Propene, see Propylene                           |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| iso-Propenyl acetate                             | 0.91             | 3.45                     | 16                              | –                   | 1.9–                                | 93                 | –93                | sl. sol.                      | –                           |
| β-Propiolactone, see Hydracrylic acid-β-lactone  |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Propionaldehyde                                  | 0.81             | 2.0                      | –9oc                            | 207                 | 3–16                                | 48                 | –81                | sol.                          | –                           |
| Propionic acid                                   | 0.99             | 2.56                     | 54                              | 513                 | 2.9–                                | 141                | –22                | ∞                             | 10/40                       |

|                                                      |       |      |       |                                      |          |               |          |          |           |
|------------------------------------------------------|-------|------|-------|--------------------------------------|----------|---------------|----------|----------|-----------|
| Propionitrile                                        | 0.77  | 1.9  | 2     | –                                    | 3.1–     | 97            | –93      | v. sol.  | –         |
| Propionyl chloride                                   | 1.06  | 3.2  | 12    | –                                    | –        | 80            | –94      | dec.     | –         |
| iso-Propyl acetate                                   | 0.87  | 3.52 | 4     | 460                                  | 1.8–7.8  | 93            | –73      | sol.     | –         |
| <i>n</i> -Propyl acetate                             | 0.89  | 3.5  | 14    | 450                                  | 2–8      | 102           | –95      | sl. sol. | 40/29     |
| <i>n</i> -Propyl alcohol                             | 0.78  | 2.07 | 15    | 433                                  | 2.1–13.5 | 97            | –127     | v. sol.  | 10/15     |
| iso-Propyl alcohol                                   | 0.79  | 2.07 | 12    | 399                                  | 2.3–12.7 | 82            | –89      | ∞        | –         |
| Propylamine                                          | 0.72  | 2.0  | –37   | 318                                  | 2.0–10.4 | 49            | –83      | sol.     | 248/20    |
| iso-Propylamine                                      | 0.69  | 2.03 | –37oc | 402                                  | 2.3–10.4 | 32            | –101     | ∞        | –         |
| Propyl benzene                                       | 0.86  | 4.14 | 30    | 450                                  | 0.8–6    | 159           | –100     | insol.   | 10/43     |
| iso-Propyl benzene, <i>see</i> Cumene                |       |      |       |                                      |          |               |          |          |           |
| iso-Propyl benzoate                                  | 1.01  | 5.67 | 99    | –                                    | –        | 218           | –26      | insol.   | –         |
| Propyl bromide                                       | 1.35  | 4.3  | –     | 490                                  | –        | 71            | –110     | sl. sol. | –         |
| Propyl chloride                                      | 0.89  | 2.71 | <–18  | 520                                  | 2.6–11.1 | 47            | –123     | sl. sol. | –         |
| <i>n</i> -Propyl cyanide, <i>see</i> Butyronitrile   |       |      |       |                                      |          |               |          |          |           |
| Propylene                                            | 0.51  | 1.5  | –108  | 460                                  | 2–11.1   | –48           | –185     | v. sol.  | 10 atm/20 |
| Propylene carbonate                                  | 1.21  | 3.5  | 135oc | –                                    | –        | 242           | –49      | v. sol.  | 0.03/20   |
| Propylene dichloride, <i>see</i> 1,2-Dichloropropane |       |      |       |                                      |          |               |          |          |           |
| iso-Propyl ether                                     | 0.72  | 3.5  | –28   | 443                                  | 1.4–21   | 69            | –60      | sl. sol. | 150/25    |
| <i>n</i> -Propyl formate                             | 0.91  | 3.03 | –3    | 455                                  | 2.3–     | 81            | –93      | sl. sol. | 100/30    |
| iso-Propyl formate                                   | 0.88  | 3.0  | –6    | 485                                  | –        | 68            | –        | sl. sol. | –         |
| iso-Propyl glycidyl ether                            | 0.92  | 4.15 | –     | –                                    | –        | 137           | –        | –        | –         |
| Propyl nitrate                                       | 1.06  | –    | 20    | 177                                  | 2–100    | 111           | <–100    | sl. sol. | –         |
| iso-Propyl toluene, <i>see</i> Cymene                |       |      |       |                                      |          |               |          |          |           |
| Propyne                                              | 0.68  | 1.38 | –     | –                                    | 1.7      | –23           | –105     | sl. sol. | 3876/20   |
| Pyridine                                             | 0.99  | 2.7  | 20    | 482                                  | 1.8–12.4 | 115           | –42      | ∞        | 10/13     |
| Pyrrolidine                                          | 0.85  | 2.45 | 3     | –                                    | –        | 89            | –63      | ∞        | 128/39    |
| Pyruvic acid                                         | 1.23  | –    | 3.0   | –                                    | –        | 165           | 14       | ∞        | –         |
| Quinoline                                            | 1.09  | 4.45 | –     | 480                                  | 1.2–     | 238           | –20      | sol.     | 1/60      |
| Quinone                                              | 1.32  | –    | 293   | –                                    | –        | –             | 116subl. | sl. sol. | –         |
| Resorcinol                                           | 1.27  | 3.79 | 127   | 608                                  | 1.4–     | 281           | 110      | sol.     | 1/108     |
|                                                      |       |      |       |                                      | at 200 C |               |          |          |           |
| Salicylaldehyde                                      | 1.15  | –    | 78    | –                                    | –        | 197           | –10      | sl. sol. | 1/33      |
| Salicylic acid                                       | 1.44  | 4.8  | 157   | 545                                  | –        | 211 at 203 mm | 159      | sl. sol. | 1/114     |
| Silane                                               | 0.68  | –    | –     | Spontaneously flammable in air       | –112     | –185          | insol.   | –        | –         |
| Sodium                                               | 0.97  | –    | –     | >115 spontaneous ignition in dry air |          | 892           | 98       | dec.     | –         |
| Sodium acetate                                       | 1.53  | –    | –     | 607                                  | –        | –             | 324      | 119      | –         |
| Stearic acid                                         | 0.95  | 9.8  | 196   | 395                                  | –        | 358–83        | 69       | insol.   | 1/174     |
| Stoddard solvent                                     | 1.0   | –    | 38–43 | 227–60                               | 0.8–5    | 220–300       | –        | –        | –         |
| Styrene                                              | 0.909 | 3.6  | 31    | 490                                  | 1.1–6.1  | 146           | –33      | insol.   | –         |
| Styrene monomer                                      | 0.905 | 1    | 31    | 490                                  | 1.1–6.1  | 145           | –31      | insol.   | –         |
| Succinonitrile                                       | 0.98  | 2.1  | 132   | –                                    | –        | 266           | 58       | v. sol.  | 2/100     |

Table 6.1 Cont'd

| Substance                                   | Specific gravity | Vapour density (air = 1) | Flash point <sup>(1)</sup> (°C) | Ignition temp. (°C) | Flammable limits <sup>(1)</sup> (%) | Boiling point (°C) | Melting point (°C) | Solubility in water (g/100 g) | Vapour pressure (mm Hg/ °C) |
|---------------------------------------------|------------------|--------------------------|---------------------------------|---------------------|-------------------------------------|--------------------|--------------------|-------------------------------|-----------------------------|
| Sulphur                                     | 2.07             | –                        | 207                             | 232                 | –                                   | 444                | 119                | insol.                        | 1/184                       |
| Sulphur monochloride                        | 1.69             | 4.7                      | 118                             | 234                 | –                                   | 136                | –80                | dec.                          | 10/28                       |
| Tallow                                      | 0.895            | –                        | 265                             | –                   | –                                   | –                  | 32                 | –                             | –                           |
| Tannic acid                                 | –                | –                        | 199oc                           | 527                 | –                                   | –                  | 210dec.            | sol.                          | –                           |
| <i>m</i> -Terphenyl                         | 1.16             | –                        | 135oc                           | –                   | –                                   | 365                | 87                 | insol.                        | –                           |
| <i>o</i> -Terphenyl                         | 1.14             | 7.9                      | 163oc                           | –                   | –                                   | 332                | 57                 | insol.                        | –                           |
| 1,2,4,5-Tetrachlorobenzene                  | 1.86             | –                        | 155                             | –                   | –                                   | 243                | 139                | insol.                        | <0.1/25                     |
| Tetradecane                                 | 0.76             | 6.8                      | 100                             | 202                 | 0.5–                                | 254                | 6                  | insol.                        | 1/76                        |
| Tetraethylenepentamine                      | 0.99             | –                        | 163oc                           | –                   | –                                   | 333                | –                  | –                             | –                           |
| Tetraethyl lead                             | 1.66             | 8.6                      | 93                              | –                   | –                                   | 170exp.            | –137               | insol.                        | 1/38                        |
| Tetrahydrofuran                             | 0.89             | 2.5                      | –14                             | 321                 | 2–11.8                              | 65                 | –65                | v. sol.                       | 114/15                      |
| Tetrahydronaphthalene                       | 0.97             | 4.55                     | 71                              | 384                 | 0.8–5<br>at 150 °C                  | 207                | –30                | insol.                        | 1/38                        |
| 2,2'-Thiodiethanol                          | 1.18             | 4.2                      | 160oc                           | –                   | –                                   | 28                 | –11                | ∞                             | –                           |
| Thiophene                                   | 1.06             | 2.9                      | –1                              | –                   | –                                   | 84                 | –38                | –                             | 40/12                       |
| Toluene                                     | 0.87             | 3.1                      | 4.4                             | 536                 | 1.4–6.7                             | 111                | –95                | insol.                        | 37/30                       |
| Toluene-2,4-diisocyanate                    | 1.2              | 6.0                      | 132                             | –                   | 0.9–9.5                             | 251                | 20                 | –                             | –                           |
| <i>m</i> -Toluidine                         | 0.99             | 3.9                      | 86                              | 482                 | –                                   | 203                | –31                | sl. sol.                      | 1/41                        |
| <i>o</i> -Toluidine                         | 1.004            | 3.7                      | 85                              | 482                 | –                                   | 200                | –16                | sl. sol.                      | 1/44                        |
| <i>p</i> -Toluidine                         | 1.046            | 3.9                      | 87                              | 482                 | –                                   | 200                | 44                 | sl. sol.                      | 1/42                        |
| Triamylamine                                | 0.8              | 7.8                      | 102                             | –                   | –                                   | 232                | –                  | –                             | –                           |
| Tri- <i>n</i> -butyl amine                  | 0.8              | 6.38                     | 86                              | –                   | –                                   | 216                | –70                | sl. sol.                      | –                           |
| Tributyl phosphate                          | 0.97             | 9.2                      | 146                             | –                   | –                                   | 292                | <–80               | sol.                          | –                           |
| 1,2,4-Trichlorobenzene                      | 1.45             | 6.3                      | 99                              | –                   | –                                   | 214                | 17                 | insol.                        | 1/38                        |
| 1,1,1-Trichloroethane                       | 1.34             | 4.6                      | none                            | –                   | –                                   | 74                 | –38                | insol.                        | 100/20                      |
| Trichloroethylene                           | 1.46             | 4.54                     | –                               | 410                 | 12–90                               | 87                 | –73                | sl. sol.                      | 100/32                      |
| 1,2,3-Trichloropropane                      | 1.39             | 5.0                      | 82                              | 304                 | 3.2–12.6                            | 156                | –15                | sl. sol.                      | 100/46                      |
| 1,1,2-Trichloro-1,2,2-trifluoroethane       | 1.56             | –                        | –                               | 680                 | –                                   | 48                 | –36                | insol.                        | –                           |
| Tricresyl phosphate, see Tritolyl phosphate |                  |                          |                                 |                     |                                     |                    |                    |                               |                             |
| Tridecanol                                  | 0.82             | 6.9                      | 121                             | –                   | –                                   | 274                | 31                 | insol.                        | –                           |
| Triethyl aluminium                          | 0.84             | –                        | <–53                            | <–53                | –                                   | 194                | –53                | exp. H <sub>2</sub> O         | 4/83                        |
| Triethyl amine                              | 0.73             | 3.48                     | <–7                             | –                   | 1.2–8.0                             | 89                 | –115               | sol.                          | –                           |
| Triethanolamine                             | 1.13             | –                        | 179                             | –                   | –                                   | 360                | 20                 | ∞                             | 10/205                      |
| Triethylene glycol                          | 1.13             | 5.17                     | 177                             | 371                 | 0.9–9.2                             | 276                | –4                 | ∞                             | 1/114                       |
| Triethylene-tetramine                       | 0.98             | –                        | 135                             | 338                 | –                                   | 267                | 12                 | sol.                          | <0.01/20                    |
| Triethyl <i>o</i> -formate                  | 0.89             | 5.1                      | 30                              | –                   | –                                   | 146                | –                  | dec.                          | 10/40                       |
| Triisobutyl aluminium                       | 0.79             | –                        | <0                              | <4                  | –                                   | 114                | 4                  | –                             | –                           |

|                                                  |      |      |       |     |          |         |      |          |         |
|--------------------------------------------------|------|------|-------|-----|----------|---------|------|----------|---------|
| Trimethyl amine                                  | 0.66 | 2.0  | −7    | 190 | 2−11.6   | 4       | −117 | v. sol.  | −       |
| Trimethyl borate                                 | 0.92 | 3.6  | <27   | −   | −        | 67      | −29  | dec.     | −       |
| 3,5,5-Trimethyl-2-cyclohexenone, see iso-Phorone |      |      |       |     |          |         |      |          |         |
| 2,2,4-Trimethyl pentane                          | 0.69 | 3.9  | −12   | 418 | 1.1−6.0  | 99      | −107 | insol.   | 41/21   |
| 2,4,4-Trimethyl-2-pentene                        | 0.72 | 3.9  | 2     | −   | −        | 112     | −107 | insol.   | 77/38   |
| 1,3,5-Trioxane                                   | 1.17 | 3.1  | 45    | 414 | 3.6−29   | 115     | 62   | v. sol.  | 13/25   |
| Triphenyl phosphate                              | 1.21 | −    | 220   | −   | −        | 245     | 49   | insol.   | −       |
|                                                  |      |      |       |     |          | at 11mm |      |          |         |
| Triphenyl phosphine                              | 1.19 | 90   | 180   | −   | −        | >360    | 80   | insol.   | −       |
| Tripropylamine                                   | 0.75 | 4.9  | 41    | −   | −        | 156     | −94  | sl. sol. | −       |
| Tritolyl phosphate                               | 1.17 | 12.7 | 225   | 385 | −        | 410     | 11   | −        | −       |
| Turpentine                                       | 0.87 | 4.6  | 35−39 | 253 | 0.8−     | 153−75  | −    | −        | −       |
| Unsymmetrical dimethyl hydrazine                 | 0.79 | 1.94 | ~−15  | 249 | 2−95     | 63      | −58  | v. sol.  | −       |
| Valeraldehyde                                    | 0.81 | 3.0  | 12    | −   | −        | 102     | −92  | sl. sol. | −       |
| Valeric acid                                     | 0.94 | 3.5  | 96    | −   | −        | 186     | −35  | sol.     | −       |
| Vinyl acetate                                    | 0.94 | 3.0  | −8    | 427 | 2.6−13.4 | 73      | −100 | insol.   | 100/21  |
| Vinyl chloride                                   | 0.91 | 2.15 | −78   | 472 | 4−22     | −14     | −154 | sl. sol. | 2600/25 |
| Vinyl cyanide, see Acrylonitrile                 |      |      |       |     |          |         |      |          |         |
| Vinyl ether                                      | 0.77 | 2.4  | <−30  | 360 | 1.7−37   | 39      | −    | −        | −       |
| Vinylidene chloride                              | 1.3  | 3.4  | −15oc | 458 | 5.6−11.4 | 32      | −122 | insol.   | −       |
| Vinyl toluene, see Methyl styrene                |      |      |       |     |          |         |      |          |         |
| <i>m</i> -Xylene                                 | 0.87 | 3.7  | 29    | 528 | 1.1−7.0  | 139     | −48  | insol.   | 10/28   |
| <i>o</i> -Xylene                                 | 0.90 | 3.7  | 32    | 464 | 1.0−6.0  | 144     | −26  | insol.   | 10/32   |
| <i>p</i> -Xylene                                 | 0.86 | 3.6  | 27    | 529 | 1.1−7.0  | 138     | 13   | insol.   | 10/27   |
| Xylidine                                         | 0.99 | 4.2  | 97    | −   | −        | 224     | <−15 | sl. sol. | −       |

dec. Decomposes  
exp. Explodes on contact with water  
insol. Insoluble  
oc Open cup  
sl. sol. Slightly soluble (<5 g/100 g)  
sol. Soluble (5–50 g/100 g)  
v. sol. Very soluble (>50 g/100 g)  
∞ Infinitely soluble (soluble in all proportions)

Superscript indicates °C.

<sup>(1)</sup> Unless otherwise stated, flammable limits relate to ambient temperature and atmospheric pressure and flash points relate to closed cup measurements.

**Table 6.2 Dust explosion characteristics of combustible solids**

| <i>Dust</i>                                  | <i>Minimum ignition temperature ( C )</i> |              | <i>Minimum explosible concentration (g/l)</i> | <i>Minimum ignition energy (mJ)</i> | <i>Maximum explosion pressure (psi)<sup>(1)</sup></i> | <i>Maximum rate of pressure rise .(psi/s)</i> | <i>Maximum oxygen concentration to prevent ignition (% by volume)</i> | <i>Notes</i>                               |
|----------------------------------------------|-------------------------------------------|--------------|-----------------------------------------------|-------------------------------------|-------------------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------|
|                                              | <i>cloud</i>                              | <i>layer</i> |                                               |                                     |                                                       |                                               |                                                                       |                                            |
| Acetamide                                    | 560                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     | Group (b) dust                             |
| Aceto acetanilide                            | 560                                       | –            | 0.030                                         | 20                                  | 90                                                    | 4800                                          | –                                                                     |                                            |
| Acetoacet- <i>p</i> -phenetide               | 560                                       | –            | 0.030                                         | 10                                  | 87                                                    | >10 000                                       | –                                                                     |                                            |
| Acetoacet- <i>o</i> -toluidine               | 710                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     |                                            |
| 2-Acetylamino-5-nitro thiazole               | 450                                       | 450          | 0.160                                         | 40                                  | 137                                                   | 9000                                          | –                                                                     |                                            |
| Acetyl- <i>p</i> -nitro- <i>o</i> -toluidine | 450                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     |                                            |
| Adipic acid                                  | 550                                       | –            | 0.035                                         | 60                                  | 95                                                    | 4000                                          | –                                                                     |                                            |
| Alfalfa                                      | 460                                       | 200          | 0.100                                         | 320                                 | 88                                                    | 1100                                          | –                                                                     |                                            |
| Almond shell                                 | 440                                       | 200          | 0.065                                         | 80                                  | 101                                                   | 1400                                          | –                                                                     |                                            |
| Aluminium, atomized                          | 650                                       | 760          | 0.045                                         | 50                                  | 84                                                    | >20 000                                       | –                                                                     |                                            |
| Aluminium, flake                             | 610                                       | 320          | 0.045                                         | 10                                  | 127                                                   | >20 000                                       | –                                                                     |                                            |
| Aluminium–cobalt alloy                       | 950                                       | 570          | 0.180                                         | 100                                 | 92                                                    | 11 000                                        | –                                                                     |                                            |
| Aluminium–copper alloy                       | –                                         | 830          | 0.100                                         | 100                                 | 95                                                    | 4000                                          | –                                                                     |                                            |
| Aluminium–iron alloy                         | 550                                       | 450          | –                                             | –                                   | 36                                                    | 300                                           | –                                                                     |                                            |
| Aluminium–lithium alloy                      | 470                                       | 400          | <0.1                                          | 140                                 | 96                                                    | 6000                                          | –                                                                     |                                            |
| Aluminium–magnesium alloy                    | 430                                       | 480          | 0.020                                         | 80                                  | 86                                                    | 10 000                                        | –                                                                     |                                            |
| Aluminium–nickel alloy                       | 950                                       | 540          | 0.190                                         | 80                                  | 96                                                    | 10 000                                        | –                                                                     |                                            |
| Aluminum–silicon alloy                       | 670                                       | –            | 0.040                                         | 60                                  | 85                                                    | 7500                                          | –                                                                     | Guncotton ignition source in pressure test |
| Aluminium acetate                            | 560                                       | 640          | –                                             | –                                   | 59                                                    | 950                                           | –                                                                     |                                            |
| Aluminium octoate                            | 460                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     |                                            |
| Aluminium stearate                           | 400                                       | 380          | 0.015                                         | 10                                  | 86                                                    | >10 000                                       | –                                                                     |                                            |
| 2-Amino-5-nitrothiazole                      | 460                                       | 460          | 0.075                                         | 30                                  | 110                                                   | 5600                                          | –                                                                     |                                            |
| Anthracene                                   | 505                                       | Melts        | –                                             | –                                   | 68                                                    | 700                                           | –                                                                     |                                            |
| Anthranilic acid                             | 580                                       | –            | 0.030                                         | 35                                  | 84                                                    | 6500                                          | –                                                                     |                                            |
| Anthraquinone                                | 670                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     |                                            |
| Antimony                                     | 420                                       | 330          | 0.420                                         | 1920                                | 28                                                    | 300                                           | –                                                                     |                                            |
| Antipyrin                                    | 405                                       | Melts        | –                                             | –                                   | 53                                                    | –                                             | –                                                                     |                                            |
| Asphalt                                      | 510                                       | 500          | 0.025                                         | 25                                  | 94                                                    | 4800                                          | –                                                                     |                                            |
| Aspirin                                      | 550                                       | Melts        | 0.015                                         | 16                                  | 87                                                    | 7700                                          | –                                                                     |                                            |
| Azelaic acid                                 | 610                                       | –            | 0.025                                         | 25                                  | 76                                                    | 4700                                          | –                                                                     |                                            |
| $\alpha$ , $\alpha'$ -Azo isobutyronitrile   | 430                                       | 350          | 0.015                                         | 25                                  | 134                                                   | 8000                                          | –                                                                     |                                            |
| Barley                                       | 370                                       | –            | –                                             | –                                   | –                                                     | –                                             | –                                                                     |                                            |
| Benzethonium chloride                        | 380                                       | 410          | 0.020                                         | 60                                  | 91                                                    | 6700                                          | –                                                                     |                                            |
| Benzoic acid                                 | 600                                       | Melts        | 0.011                                         | 12                                  | 95                                                    | 10 300                                        | –                                                                     |                                            |
| Benzotriazole                                | 440                                       | –            | 0.030                                         | 30                                  | 103                                                   | 9200                                          | –                                                                     |                                            |



|                                              |                |     |                |      |                |         |    |                                                                             |
|----------------------------------------------|----------------|-----|----------------|------|----------------|---------|----|-----------------------------------------------------------------------------|
| Benzoyl peroxide                             | –              | –   | –              | 21   | –              |         |    |                                                                             |
| Beryllium                                    | 910            | 540 |                | –    | Did not ignite |         | –  | Contained 8% oxide                                                          |
| Beryllium acetate, basic                     | 620            | –   | 0.080          | 100  | 87             | 2200    | 15 | Inert gas carbon dioxide                                                    |
| Bis(2-hydroxy-5-chlorophenyl)-methane        | 570            | –   | 0.040          | 60   | 70             | 2000    | 13 | Inert gas carbon dioxide                                                    |
| Bis(2-hydroxy-3,5,6-trichlorophenyl)-methane | Did not ignite | 450 |                |      |                |         |    |                                                                             |
| Bone meal                                    | 490            | 230 |                |      | 11             | 100     |    | Guncotton ignition source in pressure test                                  |
| Boron                                        | 730            | 390 | Did not ignite |      | 41             | 200     |    | Guncotton ignition source in pressure test                                  |
| Bread                                        | 450            |     |                |      |                |         |    |                                                                             |
| Brunswick green                              | 360            |     |                |      |                |         |    |                                                                             |
| <i>t</i> -butyl benzoic acid                 | 560            | –   | 0.020          | 25   | 88             | 6500    | –  |                                                                             |
| Cadmium                                      | 570            | 250 |                | 4000 | 7              | 100     |    |                                                                             |
| Cadmium yellow                               | 390            |     |                |      |                |         |    |                                                                             |
| Calcium carbide                              | 555            | 325 |                |      | 13             |         |    |                                                                             |
| Calcium citrate                              | 470            |     |                |      |                |         |    | Group (b) dust                                                              |
| Calcium gluconate                            | 550            |     |                |      |                |         |    | Group (b) dust                                                              |
| Calcium DL pantothenate                      | 520            | –   | 0.050          | 80   | 105            | 4600    | –  |                                                                             |
| Calcium propionate                           | 530            | –   | –              | –    | 90             | 1900    | –  |                                                                             |
| Calcium silicide                             | 540            | 540 | 0.060          | 150  | 86             | 20 000  | –  |                                                                             |
| Calcium stearate                             | 400            |     | 0.025          | 15   | 97             | >10 000 | –  |                                                                             |
| Caprolactam                                  | 430            | –   | 0.07           | 60   | 79             | 1700    | 8  |                                                                             |
| Carbon, activated                            | 660            | 270 | 0.100          | –    | 92             | 1700    | –  | Guncotton ignition source in min. expl. conc. and max. expl. pressure tests |
| Carbon, black                                | 510            |     |                |      |                |         |    |                                                                             |
| Carboxy methyl cellulose                     | 460            | 310 | 0.060          | 140  | 130            | 5000    |    |                                                                             |
| Carboxy methyl hydroxy ethyl cellulose       | 380            | –   | 0.200          | 960  | 83             | 800     | –  |                                                                             |
| Carboxy polymethylene                        | 520            | –   | 0.115          | 640  | 76             | 1200    | –  |                                                                             |
| Casein                                       | 460            | –   | –              | –    | 89             | 1200    | –  |                                                                             |
| Cellulose                                    | 410            | 300 | 0.045          | 40   | 117            | 8000    | –  |                                                                             |
| Cellulose acetate                            | 340            | –   | 0.035          | 20   | 114            | 6500    | 5  | Inert gas nitrogen                                                          |
| Cellulose acetate butyrate                   | 370            | –   | 0.025          | 30   | 81             | 2700    | 7  |                                                                             |
| Cellulose propionate                         | 460            | –   | 0.025          | 60   | 105            | 4700    | –  |                                                                             |
| Cellulose triacetate                         | 390            |     | 0.035          | 30   | 107            | 4300    | –  |                                                                             |
| Cellulose tripropionate                      | 460            | –   | 0.025          | 45   | 88             | 4000    | –  |                                                                             |
| Charcoal                                     | 530            | 180 | 0.140          | 20   | 100            | 1800    | –  |                                                                             |
| Chloramine-T                                 | 540            | 150 | –              | –    | 7              | 150     | –  | Guncotton ignition source in pressure test                                  |

Table 6.2 Cont'd

| Dust                                                | Minimum ignition temperature (°C) |       | Minimum explosible concentration (g/l) | Minimum ignition energy (mJ) | Maximum explosion pressure (psi) <sup>(1)</sup> | Maximum rate of pressure rise (psi/s) | Maximum oxygen concentration to prevent ignition (% by volume) | Notes                                                                       |
|-----------------------------------------------------|-----------------------------------|-------|----------------------------------------|------------------------------|-------------------------------------------------|---------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------|
|                                                     | cloud                             | layer |                                        |                              |                                                 |                                       |                                                                |                                                                             |
| <i>o</i> -Chlorobenzmalono nitrile                  |                                   |       | 0.025                                  |                              | 90                                              | >10 000                               |                                                                |                                                                             |
| <i>o</i> -Chloroaceto acetanilide                   | 640                               |       | 0.035                                  | 30                           | 94                                              | 3900                                  | —                                                              |                                                                             |
| <i>p</i> -Chloroaceto acetanilide                   | 650                               | —     | 0.035                                  | 20                           | 85                                              | 5500                                  | —                                                              |                                                                             |
| Chloro amino toluene sulphonic acid                 | 650                               | —     | —                                      | —                            | —                                               | —                                     | —                                                              |                                                                             |
| 4-Chloro-2 nitro aniline                            | 590                               | 120   | <0.750                                 | 140                          | 123                                             | 3500                                  | —                                                              |                                                                             |
| <i>p</i> -Chloro- <i>o</i> -toluidine hydrochloride | 650                               | —     | —                                      | —                            | —                                               | —                                     | —                                                              |                                                                             |
| Chocolate crumb                                     | 340                               | —     | —                                      | —                            | —                                               | —                                     | —                                                              |                                                                             |
| Chromium                                            | 580                               | 400   | —                                      | 140                          | 56                                              | 5000                                  | —                                                              |                                                                             |
| Cinnamon                                            | 440                               | 230   | 0.230                                  | 30                           | 121                                             | 3900                                  | —                                                              |                                                                             |
| Citrus peel                                         | 500                               | 330   | 0.060                                  | 100                          | 51                                              | 1200                                  | —                                                              |                                                                             |
| Coal, brown                                         | 485                               | 230   | 0.060                                  |                              |                                                 | —                                     | —                                                              | See also Lignite                                                            |
| Coal, 8% volatiles                                  | 730                               |       |                                        | —                            |                                                 | —                                     | —                                                              |                                                                             |
| Coal, 12% volatiles                                 | 670                               | 240   | —                                      |                              |                                                 | —                                     | —                                                              |                                                                             |
| Coal, 25% volatiles                                 | 605                               | 210   | 0.120                                  | 120                          | 62                                              | 400                                   | —                                                              |                                                                             |
| Coal, 37% volatiles                                 | 610                               | 170   | 0.055                                  | 60                           | 90                                              | 2300                                  | —                                                              | Standard Pittsburgh coal                                                    |
| Coal, 43% volatiles                                 | 575                               | 180   | 0.050                                  | 50                           | 92                                              | 2000                                  | —                                                              |                                                                             |
| Cobalt                                              | 760                               | 370   | —                                      | —                            |                                                 | —                                     | —                                                              |                                                                             |
| Cocoa                                               | 500                               | 200   | 0.065                                  | 120                          | 69                                              | 1200                                  | —                                                              |                                                                             |
| Coconut                                             | 450                               | 280   | —                                      | —                            |                                                 | —                                     | —                                                              |                                                                             |
| Coconut shell                                       | 470                               | 220   | 0.035                                  | 60                           | 115                                             | 4200                                  | —                                                              |                                                                             |
| Coffee                                              | 360                               | 270   | 0.085                                  | 160                          | 38                                              | 150                                   | 10                                                             | Inert gas carbon dioxide                                                    |
| Coffee, extract                                     | 600                               | —     | —                                      | —                            | 47                                              | —                                     | —                                                              |                                                                             |
| Coffee, instant                                     | 410                               | 350   | 0.280                                  | Did not ignite               | 68                                              | 500                                   | —                                                              |                                                                             |
| Coke                                                | >750                              | 430   | —                                      | —                            | —                                               | —                                     | —                                                              |                                                                             |
| Coke, petroleum, 13% volatiles                      | 670                               |       | 1.00                                   |                              | 36                                              | 200                                   | —                                                              | Guncotton ignition source in min. expl. conc. and max. expl. pressure tests |
| Colophony                                           | 325                               | Melts |                                        | —                            |                                                 |                                       | —                                                              |                                                                             |
| Copal                                               | 330                               | Melts |                                        | —                            | 68                                              | —                                     | —                                                              | See also Gum manila                                                         |
| Copper                                              | 700                               | —     | —                                      | Did not ignite               | Did not ignite                                  | Did not ignite                        | —                                                              |                                                                             |

|                                                      |     |       |       |      |     |         |    |                |
|------------------------------------------------------|-----|-------|-------|------|-----|---------|----|----------------|
| Copper–zinc, gold bronze                             | 370 | 190   | 1.00  | –    | 44  | 1300    | –  |                |
| Cork                                                 | 460 | 210   | 0.035 | 35   | 96  | 7500    |    |                |
| Corn cob                                             | 450 | 240   | 0.045 | 45   | 127 | 3700    |    |                |
| Corn dextrine                                        | 410 | 390   | 0.040 | 40   | 124 | 7000    |    |                |
| Cornflour                                            | 390 | –     | –     | –    | –   | –       | –  |                |
| Cornstarch                                           | 390 |       | 0.040 | 30   | 145 | 9500    |    |                |
| Cotton flock                                         | 470 | –     | 0.050 | 25   | 94  | 6000    |    |                |
| Cotton linters                                       | 520 |       | 0.50  | 1920 | 73  | 400     | 5  |                |
| Cottonseed meal                                      | 530 | 200   | 0.055 | 80   | 89  | 2200    | –  |                |
| Coumarone–indene resin                               | 550 | –     | 0.015 | 10   | 93  | 11 000  | 11 |                |
| Crystal violet                                       | 475 | Melts | –     | –    | –   | –       | –  |                |
| Cyclohexanone peroxide                               | –   | –     | –     | 21   | 84  | 5600    | –  |                |
| Dehydroacetic acid                                   | 430 | –     | 0.030 | 15   | 87  | 8000    | –  |                |
| Dextrin                                              | 410 | 440   | 0.050 | 40   | 99  | 9000    |    |                |
| Dextrose monohydrate                                 | 350 | –     | –     |      | –   | –       | –  |                |
| Diallyl phthalate                                    | 480 | –     | 0.030 | 20   | 90  | 8500    | –  |                |
| Diamino stilbene disulphonic acid                    | 550 | –     |       |      |     | –       | –  | Group (b) dust |
| Diazo aminobenzene                                   | 550 | –     | 0.015 | 20   | 114 | >10 000 | –  |                |
| Di- <i>t</i> -butyl- <i>p</i> -cresol                | 420 |       | 0.015 | 15   | 79  | 13 000  | 9  |                |
| Dibutyl tin maleate                                  | 600 | –     |       |      |     |         |    |                |
| Dibutyl tin oxide                                    | 530 |       |       |      |     |         |    |                |
| Dichlorophene                                        | 770 |       |       |      | 72  | 3000    |    |                |
| 2,4-Dichlorophenoxy ethyl benzoate                   | 540 |       | 0.045 | 60   | 84  | 2200    |    |                |
| Dicyclopentadiene dioxide                            | 420 |       | 0.015 | 30   | 89  | 9500    |    |                |
| Dihydrostreptomycin sulphate                         | 600 | 230   | 0.520 | –    | 42  | 200     | 7  |                |
| 3,3'-Dimethoxy 4,4'-diamino diphenyl                 | –   | –     | 0.030 |      | 82  | >10 000 | –  |                |
| Dimethylacridan                                      | 540 |       |       |      |     |         | –  |                |
| Dimethyl diphenyl urea                               | 490 |       |       |      |     |         |    |                |
| Dimethyl isophthalate                                | 580 |       | 0.025 | 15   | 84  | 8000    |    |                |
| Dimethyl terephthalate                               | 570 |       | 0.030 | 20   | 105 | 12 000  | 6  |                |
| S-S'-Dimethyl xanthogene thylene bis dithiocarbamate | 400 |       | 0.300 | 3200 | 84  | 1500    |    |                |
| Dinitro aniline                                      | 470 |       |       | –    |     |         |    |                |
| 3,5-Dinitrobenzamide                                 | 500 | Melts | 0.040 | 45   | 163 | 6500    | –  |                |
| 3,5-Dinitrobenzoic acid                              | 460 | –     | 0.050 | 45   | 139 | 4300    |    |                |
| Dinitrobenzoyl chloride                              | 380 | –     | –     | –    | –   | –       | –  |                |
| Dinitrocresol                                        | 340 | Melts | 0.030 | –    |     |         |    |                |
| 4,4'-Dinitro-sym-diphenyl urea                       | 550 | –     | 0.095 | 60   | 102 | 2500    | –  |                |
| Dinitro stilbene disulphonic acid                    | 450 | –     | –     | –    | –   | –       | –  |                |
| Dinitrotoluanide                                     | 500 | –     | 0.050 | 15   | 153 | >10 000 | –  |                |
| Diphenyl                                             | 630 | –     | 0.015 | 20   | 82  | 3700    | –  |                |

Table 6.2 Cont'd

| Dust                               | Minimum ignition temperature (°C) |       | Minimum explosible concentration (g/l) | Minimum ignition energy (mJ) | Maximum explosion pressure (psi) <sup>(1)</sup> | Maximum rate of pressure rise (psi/s) | Maximum oxygen concentration to prevent ignition (% by volume) | Notes              |
|------------------------------------|-----------------------------------|-------|----------------------------------------|------------------------------|-------------------------------------------------|---------------------------------------|----------------------------------------------------------------|--------------------|
|                                    | cloud                             | layer |                                        |                              |                                                 |                                       |                                                                |                    |
| 4,4'-Diphenyl di sulphonylazide    | 590                               | 140   | 0.065                                  | 30                           | 143                                             | 5500                                  |                                                                |                    |
| Diphenylol propane (Bisphenol-A)   | 570                               |       | 0.012                                  | 11                           | 81                                              | 11 800                                | 5                                                              | Inert gas nitrogen |
| Egg white                          | 610                               | –     | 0.14                                   | 640                          | 58                                              | 500                                   |                                                                |                    |
| Epoxy resin                        | 490                               | –     | 0.015                                  | 9                            | 94                                              | 8500                                  | –                                                              |                    |
| Esparto grass                      | –                                 | –     | –                                      | –                            | 94                                              | 7300                                  | –                                                              |                    |
| Ethyl cellulose                    | 340                               | 330   | 0.025                                  | 15                           | 112                                             | 7000                                  |                                                                |                    |
| Ethylene diamine tetra acetic acid | 450                               | –     | 0.075                                  | 50                           | 106                                             | 3000                                  |                                                                |                    |
| Ethyl hydroxyethyl cellulose       | 390                               | –     | 0.020                                  | 30                           | 94                                              | 2200                                  |                                                                |                    |
| Ferric ammonium ferrocyanide       | 390                               | 210   | 1.500                                  |                              | 17                                              | 100                                   |                                                                |                    |
| Ferric dimethyl dithio carbamate   | 280                               | 150   | 0.055                                  | 25                           | 86                                              | 6300                                  |                                                                |                    |
| Ferric ferrocyanide                | 370                               |       |                                        |                              | 82                                              | 1000                                  |                                                                |                    |
| Ferrochromium                      | 790                               | 670   | 2.00                                   |                              |                                                 |                                       |                                                                |                    |
| Ferromanganese                     | 450                               | 290   | 0.130                                  | 80                           | 62                                              | 5000                                  |                                                                |                    |
| Ferrosilicon (45% Si)              | 640                               |       |                                        |                              |                                                 |                                       |                                                                |                    |
| Ferrosilicon (90% Si)              | Did not ignite                    | 980   | 0.240                                  | 1280                         | 113                                             | 3500                                  |                                                                |                    |
| Ferrotitanium                      | 370                               | 400   | 0.140                                  | 80                           | 55                                              | 9500                                  |                                                                |                    |
| Ferrous ferrocyanide               | 380                               | 190   | 0.400                                  |                              |                                                 |                                       |                                                                |                    |
| Ferrovandium                       | 440                               | 400   | 1.300                                  | 400                          |                                                 |                                       |                                                                |                    |
| Fish meal                          | 485                               |       |                                        |                              |                                                 |                                       |                                                                |                    |
| Fumaric acid                       | 520                               |       | 0.085                                  | 35                           | 103                                             | 3000                                  | –                                                              |                    |
| Garlic                             | 360                               | –     | 0.10                                   | 240                          | 57                                              | 1300                                  | –                                                              |                    |
| Gelatin, dried                     | 620                               | 480   | <0.5                                   | –                            | 78                                              | 1200                                  | –                                                              |                    |
| Gilsonite                          | 580                               | 500   | 0.020                                  | 25                           | 78                                              | 4500                                  |                                                                |                    |
| Graphite                           | 730                               | 580   |                                        |                              |                                                 | –                                     |                                                                |                    |
| Grass                              |                                   |       |                                        |                              | 56                                              | 400                                   |                                                                |                    |
| Gum arabic                         | 500                               | 260   | 0.060                                  | 100                          | 117                                             | 3000                                  |                                                                |                    |
| Gum Karaya                         | 520                               | 240   | 0.100                                  | 180                          | 116                                             | 2500                                  | –                                                              |                    |
| Gum manila (copal)                 | 360                               | 390   | 0.030                                  | 30                           | 89                                              | 6000                                  |                                                                |                    |
| Gum tragacanth                     | 490                               | 260   | 0.040                                  | 45                           | 123                                             | 5000                                  | –                                                              |                    |
| Hexa methylene tetramine           | 410                               | –     | 0.015                                  | 10                           | 98                                              | 11 000                                | 11                                                             |                    |
| Horseradish                        | –                                 | –     | <0.100                                 |                              | 96                                              | 1600                                  |                                                                |                    |

|                                                     |     |       |                |                |     |        |   |                                        |
|-----------------------------------------------------|-----|-------|----------------|----------------|-----|--------|---|----------------------------------------|
| Hydrazine acid tartrate                             | 570 |       | 0.175          | 460            | 30  | 200    | – |                                        |
| <i>p</i> -Hydroxy benzoic acid                      | 620 | –     | 0.040          | –              | 37  | –      | – |                                        |
| Hydroxyethyl cellulose                              | 410 | –     | 0.025          | 40             | 106 | 2600   | – |                                        |
| Hydroxyethyl methyl cellulose                       | 410 |       |                |                |     |        | – |                                        |
| Hydroxy propyl cellulose                            | 400 | –     | 0.020          | 30             | 96  | 2900   | – |                                        |
| Iron                                                | 430 | 240   | –              | –              | –   | –      |   |                                        |
| Iron, carbonyl                                      | 420 | 230   | 0.105          | 100            | 47  | 8000   |   |                                        |
| Iron pyrites                                        | 380 | 280   | 1.00           | 8200           | 5   | 100    | – |                                        |
| Isatoic anhydride                                   | 700 |       | 0.035          | 25             | 80  | 4900   | – |                                        |
| Isinglass                                           | 520 | –     | –              |                | Nil | Nil    |   |                                        |
| Isophthalic acid                                    | 700 | –     | 0.035          | 25             | 78  | 3100   |   |                                        |
| Kelp                                                | 570 | 220   | Did not ignite |                | 19  | 200    | – |                                        |
| Lactalbumin                                         | 570 | 240   | 0.040          | 50             | 97  | 3500   | – |                                        |
| Lampblack                                           | 730 | –     | –              | –              |     | –      | – |                                        |
| Lauryl peroxide                                     |     |       |                | 12             | 90  | 6400   |   |                                        |
| Lead                                                | 790 | 290   |                | Did not ignite | 3   | 100    | – | Flame ignition source in pressure test |
| Leather                                             | 390 |       |                | –              |     |        |   |                                        |
| Lignin                                              | 450 |       | 0.040          | 20             | 102 | 5000   | 7 |                                        |
| Lignite                                             | 450 | 200   | 0.030          | 30             | 94  | 8000   | – |                                        |
| Lycopodium                                          | 480 | 310   | 0.025          | 40             | 75  | 3100   | 9 |                                        |
| Magnesium                                           | 560 | 430   | 0.030          | 40             | 116 | 15 000 |   |                                        |
| Maize husk                                          | 430 |       | –              | –              | 75  | 700    |   |                                        |
| Maize starch                                        | 410 | –     | –              | –              | –   | –      | – |                                        |
| Maleic anhydride                                    | 500 | Melts | –              | –              | –   | –      | – |                                        |
| Malt barley                                         | 400 | 250   | 0.055          | 35             | 95  | 4400   |   |                                        |
| Manganese                                           | 460 | 240   | 0.125          | 305            | 53  | 4900   | – |                                        |
| Manganese ethylene bis dithio carbamate             | 270 | –     | 0.07           | 35             |     | –      |   |                                        |
| Manioc                                              | 430 |       |                |                |     | –      |   |                                        |
| Mannitol                                            | 460 |       | 0.065          | 40             | 97  | 2800   |   |                                        |
| Melamine formaldehyde resin                         | 410 |       | 0.02           | 50             | 93  | 1800   |   |                                        |
| DL Methionine                                       | 370 | 360   | 0.025          | 35             | 119 | 5700   | 7 |                                        |
| 1-Methylamino anthraquinone                         | 830 | Melts | 0.055          | 50             | 71  | 3300   |   |                                        |
| Methyl cellulose                                    | 360 | 340   | 0.030          | 20             | 133 | 6000   | – |                                        |
| 2,2-Methylene bis-4-ethyl-6- <i>t</i> -butyl phenol | 310 |       |                |                | 76  | 7300   | – |                                        |
| Milk                                                | 440 | –     | –              | –              | –   | –      | – |                                        |
| Milk, skimmed                                       | 490 | 200   | 0.050          | 50             | 95  | 2300   | – |                                        |
| Milk sugar                                          | 450 | Melts | –              |                | 31  |        | – |                                        |
| Molybdenum                                          | 720 | 360   | –              |                | –   | –      | – |                                        |
| Molybdenum disulphide                               | 570 | 290   | –              | –              | –   | –      | – |                                        |
| Monochloroacetic acid                               | 620 | –     | –              | –              | –   | –      | – |                                        |
| Monosodium salt of trichloro ethyl phosphate        | 540 | –     | –              | –              | –   | –      | – | Group (b) dust                         |

Table 6.2 Cont'd

| Dust                                   | Minimum ignition temperature ( °C) |       | Minimum explosible concentration (g/l) | Minimum ignition energy (mJ) | Maximum explosion pressure (psi) <sup>(1)</sup> | Maximum rate of pressure rise (psi/s) | Maximum oxygen concentration to prevent ignition (% by volume) | Notes |
|----------------------------------------|------------------------------------|-------|----------------------------------------|------------------------------|-------------------------------------------------|---------------------------------------|----------------------------------------------------------------|-------|
|                                        | cloud                              | layer |                                        |                              |                                                 |                                       |                                                                |       |
| Moss, Irish                            | 530                                | 230   | Did not ignite                         |                              | 21                                              | 300                                   | –                                                              |       |
| Naphthalene                            | 575                                | Melts | –                                      | –                            | 87                                              | –                                     | –                                                              |       |
| β-Naphththalene-azo-dimethyl aniline   | 510                                | Melts | 0.020                                  | 50                           | 70                                              | 2300                                  | –                                                              |       |
| β-Naphthol                             | 670                                | –     | –                                      | –                            | –                                               | –                                     | –                                                              |       |
| Naphthol yellow                        | 415                                | 395   | –                                      |                              |                                                 |                                       |                                                                |       |
| Nigrosine hydrochloride                | 630                                | –     | –                                      |                              |                                                 | –                                     | –                                                              |       |
| p-Nitro-o-anisidene                    | 400                                |       |                                        |                              | –                                               |                                       |                                                                |       |
| p-Nitro-benzene arsonic acid           | 360                                | 280   | 0.195                                  | 480                          | 77                                              | 900                                   | –                                                              |       |
| Nitrocellulose                         | –                                  | –     | –                                      | 30                           | >256                                            | >20 900                               | –                                                              |       |
| Nitro diphenylamine                    | 480                                | –     | –                                      | –                            | –                                               | –                                     | –                                                              |       |
| Nitro furfural semi carbazone          | 240                                | –     | –                                      | –                            | >143                                            | 8600                                  | –                                                              |       |
| Nitropyridone                          | 430                                | Melts | 0.045                                  | 35                           | 111                                             | >10 000                               | –                                                              |       |
| p-Nitro-o-toluidine                    | 470                                | –     | –                                      | –                            | –                                               | –                                     | –                                                              |       |
| m-Nitro-p-toluidine                    | 470                                | –     | –                                      | –                            | –                                               | –                                     | –                                                              |       |
| Nylon                                  | 500                                | 430   | 0.030                                  | 20                           | 95                                              | 4000                                  | 6                                                              |       |
| Oilcake meal                           | 470                                | 285   | –                                      | –                            | –                                               | –                                     |                                                                |       |
| Onion, dehydrated                      | 410                                | –     | 0.130                                  | Did not ignite               | 35                                              | 500                                   | –                                                              |       |
| Paper                                  | 440                                | 270   | 0.055                                  | 60                           | 96                                              | 3600                                  |                                                                |       |
| Para formaldehyde                      | 410                                | –     | 0.040                                  | 20                           | 133                                             | 13 000                                |                                                                |       |
| Peanut hull                            | 460                                | 210   | 0.045                                  | 50                           | 116                                             | 8000                                  |                                                                |       |
| Peat                                   | 420                                | 295   |                                        |                              |                                                 |                                       |                                                                |       |
| Peat, sphagnum                         | 460                                | 240   | 0.045                                  | 50                           | 104                                             | 2200                                  |                                                                |       |
| Pectin                                 | 410                                | 200   | 0.075                                  | 35                           | 132                                             | 8000                                  |                                                                |       |
| Penicillin, N-ethyl piperidine salt of | 310                                |       |                                        |                              |                                                 |                                       |                                                                |       |
| Penta erythritol                       | 450                                | –     | 0.030                                  | 10                           | 90                                              | 9500                                  | 7                                                              |       |
| Phenol formaldehyde                    | 450                                |       | 0.015                                  | 10                           | 107                                             | 6500                                  |                                                                |       |
| Phenol furfural resin                  | 530                                | –     | 0.025                                  | 10                           | 88                                              | 8500                                  | –                                                              |       |
| Phenothiazine                          | 540                                | –     | 0.030                                  |                              | 56                                              | 3000                                  | –                                                              |       |
| p-Phenylene diamine                    | 620                                | –     | 0.025                                  | 30                           | 94                                              | 11 000                                | –                                                              |       |
| Phosphorus, red                        | 360                                | 305   | –                                      |                              |                                                 |                                       |                                                                |       |
| Phosphorus pentasulphide               | 280                                | 270   | 0.050                                  | 15                           | 64                                              | >10 000                               | –                                                              |       |
| Phthalic acid                          | 650                                | Melts | –                                      | –                            | 62                                              | –                                     |                                                                |       |
| Phthalic anhydride                     | 605                                | Melts | 0.015                                  | 15                           | 72                                              | 4200                                  | 11                                                             |       |

|                                   |      |       |                |     |        |         |    |                          |
|-----------------------------------|------|-------|----------------|-----|--------|---------|----|--------------------------|
| Phthalimide                       | 630  | –     | 0.030          | 50  | 89     | 4800    |    |                          |
| Phthalodinitrile                  | >700 | Melts | –              | –   | 43     | –       | –  |                          |
| Phytosterol                       | 330  | Melts | 0.025          | 10  | 76     | >10 000 |    |                          |
| Piperazine                        | 480  | –     |                |     | 72     | 1400    |    |                          |
| Pitch                             | 710  | –     | 0.035          | 20  | 88     | 6000    |    |                          |
| Polyacetal                        | 440  | –     | 0.035          | 20  | 113    | 4100    |    |                          |
| Polyacrylamide                    | 410  | 240   | 0.040          | 30  | 85     | 2500    |    |                          |
| Polyacrylonitrile                 | 500  | 460   | 0.025          | 20  | 89     | 11 000  |    |                          |
| Polycarbonate                     | 710  |       | 0.025          | 25  | 96     | 4700    | –  |                          |
| Polyethylene                      | 390  | –     | 0.020          | 10  | 80     | 7500    | –  |                          |
| Polyethylene oxide                | 350  |       | 0.030          | 30  | 106    | 2100    | 5  |                          |
| Polyethylene terephthalate        | 500  |       | 0.040          | 35  | 98     | 5500    | –  |                          |
| Poly isobutyl methacrylate        | 500  | 280   | 0.020          | 40  | 74     | 2800    | –  |                          |
| Poly methacrylic acid             | 450  | 290   | 0.045          | 100 | 97     | 1800    |    |                          |
| Polymethyl methacrylate           | 440  |       | 0.020          | 15  | 101    | 1800    | 7  |                          |
| Polymonochlorotrifluoro ethylene  | 600  | 720   | Did            | not | ignite | –       |    |                          |
| Polypropylene                     | 420  |       | 0.020          | 30  | 76     | 5500    | –  |                          |
| Polystyrene                       | 500  | 500   | 0.020          | 15  | 100    | 7000    |    |                          |
| Polytetrafluoro ethylene          | 670  | 570   | Did            | not | ignite |         |    |                          |
| Polyurethane foam                 | 510  | 440   | 0.030          | 20  | 87     | 3700    |    |                          |
| Polyurethane foam, fire retardant | 550  | 390   | 0.025          | 15  | 96     | 3700    |    |                          |
| Polyvinylacetate                  | 450  |       | 0.040          | 160 | 69     | 1000    | 11 | Inert gas carbon dioxide |
| Polyvinyl alcohol                 | 450  | Melts |                |     | 78     |         |    |                          |
| Polyvinyl butyral                 | 390  |       | 0.020          | 10  | 84     | 2000    | 5  |                          |
| Polyvinyl chloride                | 670  |       | Did not ignite |     | 38     | 500     |    | Flame ignition source    |
| Polyvinylidene chloride           | 670  |       |                |     |        |         |    | Group (b) dust           |
| Polyvinyl pyrrolidone             | 465  | Melts |                |     | 15     |         |    |                          |
| Potassium hydrogen tartrate       | 520  |       |                |     |        |         |    |                          |
| Potassium sorbate                 | 380  | 180   | 0.120          | 60  | 79     | 9500    |    |                          |
| Potato, dried                     | 450  |       |                |     | 97     | 1000    |    |                          |
| Potato starch                     | 430  |       |                |     |        |         |    |                          |
| Provender                         | 370  |       |                |     | 93     | 1400    |    |                          |
| Pyrethrum                         | 460  | 210   | 0.100          | 80  | 95     | 1500    | –  |                          |
| Quillaia bark                     | 450  |       |                |     |        |         |    |                          |
| Rape seed meal                    | 465  |       |                |     |        |         |    |                          |
| Rayon, viscose                    | 420  |       |                |     |        |         |    |                          |
| Rayon, flock                      |      |       | 0.03           |     |        |         |    |                          |
| Rice                              | 440  | 240   | 0.050          | 50  | 105    | 2700    |    |                          |
| Rosin                             | 390  |       | 0.015          | 10  | 87     | 12 000  |    |                          |
| Rubber                            | 380  |       |                |     |        |         |    |                          |
| Rubber, crude, hard               | 350  |       | 0.025          | 50  | 80     | 3800    | 13 |                          |
| Rubber, crumb                     | 440  |       |                |     | 84     | 3300    |    |                          |

Table 6.2 Cont'd

| Dust                                       | Minimum ignition temperature ( C ) |       | Minimum explosible concentration (g/l) | Minimum ignition energy (mJ) | Maximum explosion pressure (psi) <sup>(1)</sup> | Maximum rate of pressure rise .(psi/s) | Maximum oxygen concentration to prevent ignition (% by volume) | Notes                                      |
|--------------------------------------------|------------------------------------|-------|----------------------------------------|------------------------------|-------------------------------------------------|----------------------------------------|----------------------------------------------------------------|--------------------------------------------|
|                                            | cloud                              | layer |                                        |                              |                                                 |                                        |                                                                |                                            |
| Rubber, vulcanized                         | 360                                | —     | —                                      | —                            | 40                                              | —                                      |                                                                |                                            |
| Rye flour                                  | 415                                | 325   | —                                      | —                            | 35                                              | —                                      |                                                                |                                            |
| Saccharin                                  | 690                                |       |                                        |                              |                                                 |                                        |                                                                |                                            |
| Salicylanilide                             | 610                                | Melts | 0.040                                  | 20                           | 73                                              | 4800                                   | —                                                              |                                            |
| Salicylic acid                             | 590                                | —     | 0.025                                  |                              | 84                                              | 6800                                   |                                                                |                                            |
| Sawdust                                    | 430                                | —     | —                                      | —                            | 97                                              | 2000                                   | —                                                              |                                            |
| Sebacic acid                               | —                                  | —     | —                                      | —                            | 74                                              | 400                                    | —                                                              |                                            |
| Senna                                      | 440                                |       | 0.010                                  | 105                          | 49                                              | 300                                    |                                                                |                                            |
| Shellac                                    | 400                                | —     | 0.020                                  | 10                           | 73                                              | 3600                                   | 9                                                              |                                            |
| Silicon                                    | Did not ignite                     | 760   | <0.10                                  | 80                           | 94                                              | 13 000                                 | —                                                              |                                            |
| Soap                                       | 430                                | 600   | 0.085                                  | 100                          | 77                                              | 2800                                   |                                                                |                                            |
| Sodium acetate                             | 590                                |       | 0.030                                  | 35                           | 90                                              | 4600                                   |                                                                |                                            |
| Sodium amatoI                              | 580                                | Melts | 0.140                                  | —                            | 65                                              | 800                                    |                                                                |                                            |
| Sodium benzoate                            | 560                                | 680   | 0.050                                  | 80                           | 91                                              | 3700                                   |                                                                |                                            |
| Sodium carboxymethyl cellulose             | 320                                | —     | 1.10                                   | 440                          | 49                                              | 400                                    | 5                                                              |                                            |
| Sodium 2-chloro-5-nitro-benzene sulphonate | 550                                | 440   | —                                      | —                            | —                                               | —                                      | —                                                              |                                            |
| Sodium 2,2-dichloro propionate             | 500                                | —     | 0.260                                  | 220                          | 68                                              | 500                                    |                                                                |                                            |
| Sodium dihydroxy naphthalene disulphonate  | 510                                | —     | —                                      |                              |                                                 |                                        | —                                                              | Group (b) dust                             |
| Sodium glucaspaldrate                      | 600                                |       |                                        |                              |                                                 |                                        |                                                                |                                            |
| Sodium glucoheptonate                      | 600                                |       |                                        |                              |                                                 |                                        |                                                                |                                            |
| Sodium monochloracetate                    | 550                                |       |                                        |                              |                                                 |                                        | —                                                              |                                            |
| Sodium <i>m</i> -nitrobenzene sulphonate   | —                                  | —     | —                                      | —                            | 92                                              | 400                                    | —                                                              |                                            |
| Sodium <i>m</i> -nitrobenzoate             | —                                  |       |                                        |                              | 87                                              | 2900                                   | —                                                              |                                            |
| Sodium pentachlorophenate                  | Did not ignite                     | 360   |                                        |                              | Did not ignite                                  |                                        | —                                                              |                                            |
| Sodium propionate                          | 479                                |       |                                        |                              | 70                                              | 700                                    |                                                                |                                            |
| Sodium secobarbital                        | 520                                | —     | 0.100                                  | 960                          | 76                                              | 800                                    |                                                                |                                            |
| Sodium sorbate                             | 400                                | 140   | 0.050                                  | 30                           | 87                                              | 6500                                   |                                                                |                                            |
| Sodium thiosulphate                        | 510                                | 330   |                                        | —                            | 11                                              | <100                                   |                                                                | Guncotton ignition source in pressure test |



|                                                                             |      |       |                |     |                |         |                           |                    |
|-----------------------------------------------------------------------------|------|-------|----------------|-----|----------------|---------|---------------------------|--------------------|
| Sodium toluene sulphonate                                                   | 530  | –     | –              | –   | –              | –       | –                         | Inert gas nitrogen |
| Sodium xylene sulphonate                                                    | 490  | –     | –              | –   | –              | –       | –                         |                    |
| Soot                                                                        | >690 | 535   | –              | –   | Did not ignite | –       | –                         |                    |
| Sorbic acid                                                                 | 440  | 460   | 0.020          | 15  | 106            | >10 000 | 5                         |                    |
| L-Sorbose                                                                   | 370  | –     | 0.065          | 80  | 76             | 4700    | –                         |                    |
| Soya flour                                                                  | 550  | 340   | 0.060          | 100 | 94             | 800     | 9                         |                    |
| Soya protein                                                                | 540  | –     | 0.050          | 60  | 98             | 6500    | 9                         |                    |
| Starch                                                                      | 470  | –     | –              | –   | –              | –       | –                         |                    |
| Starch, cold water                                                          | 490  | –     | –              | –   | –              | –       | –                         |                    |
| Stearic acid                                                                | 290  | –     | –              | 25  | 80             | 8500    | –                         |                    |
| Steel                                                                       | 450  | –     | –              | –   | –              | –       | –                         | Group (b) dust     |
| Streptomycin sulphate                                                       | 700  | –     | –              | –   | –              | –       | –                         |                    |
| Sucrose                                                                     | 420  | Melts | 0.045          | 40  | 86             | 5500    | –                         |                    |
| Sugar                                                                       | 370  | 400   | 0.045          | 30  | 109            | 5000    | –                         |                    |
| Sulphur                                                                     | 190  | 220   | 0.035          | 15  | 78             | 4700    | –                         |                    |
| Tantalum                                                                    | 630  | 300   | <0.20          | 120 | 55             | 4400    | –                         |                    |
| Tartaric acid                                                               | 350  | –     | –              | –   | –              | –       | –                         |                    |
| Tea                                                                         | 500  | –     | –              | –   | 93             | 1700    | –                         |                    |
| Tea, instant                                                                | 580  | 340   | Did not ignite | –   | 48             | 400     | –                         |                    |
| Tellurium                                                                   | 550  | 340   | –              | –   | –              | –       | –                         |                    |
| Terephthalic acid                                                           | 680  | –     | 0.050          | 20  | 84             | 8000    | –                         |                    |
| Tetranitro carbazole                                                        | 395  | Melts | –              | –   | –              | –       | –                         |                    |
| Thiourea                                                                    | 420  | Melts | –              | –   | 29             | 100     | –                         |                    |
| Thorium                                                                     | 270  | 280   | 0.075          | 5   | 79             | 5500    | –                         |                    |
| Thorium hydride                                                             | 260  | 20    | 0.080          | 3   | 81             | 12 000  | –                         |                    |
| Tin                                                                         | 630  | 430   | 0.190          | 80  | 48             | 1700    | –                         |                    |
| Titanium                                                                    | 375  | 290   | 0.045          | 15  | 85             | 11 000  | Ignites in carbon dioxide |                    |
| Titanium hydride                                                            | 480  | 540   | 0.070          | 60  | 121            | 12 000  | 3                         |                    |
| Tobacco                                                                     | 485  | 290   | –              | –   | –              | –       | –                         |                    |
| Tobacco, dried                                                              | 320  | –     | –              | –   | 85             | 1000    | –                         |                    |
| Tobacco, stem                                                               | 420  | 230   | Did not ignite | –   | 53             | 400     | –                         |                    |
| Tribromosalicyl anilide                                                     | 880  | Melts | –              | –   | –              | –       | –                         |                    |
| Trinitrotoluene                                                             | –    | –     | 0.070          | 75  | 63             | 2100    | –                         |                    |
| s-Trioxane                                                                  | 480  | –     | 0.143          | –   | 85             | 600     | –                         |                    |
| $\alpha,\alpha'$ -Trithiobis ( <i>N</i> , <i>N</i> -dimethyl-thioformamide) | 280  | 230   | 0.060          | 35  | 96             | 6000    | –                         |                    |
| Tung                                                                        | 540  | 240   | 0.070          | 240 | 74             | 1900    | –                         |                    |
| Tungsten                                                                    | 730  | 470   | –              | –   | Did not ignite | –       | –                         |                    |
| Uranium                                                                     | 20   | 100   | 0.060          | 45  | 69             | 5000    | –                         |                    |
| Uranium hydride                                                             | 20   | 20    | 0.060          | 5   | 74             | 9000    | –                         |                    |
| Urea                                                                        | 900  | –     | Did            | not | ignite         | –       | –                         |                    |

**Table 6.2 Cont'd**

| <i>Dust</i>                       | <i>Minimum ignition temperature ( C)</i> |              | <i>Minimum explosible concentration (g/l)</i> | <i>Minimum ignition energy (mJ)</i> | <i>Maximum explosion pressure (psi)<sup>(1)</sup></i> | <i>Maximum rate of pressure rise .(psi/s)</i> | <i>Maximum oxygen concentration to prevent ignition (% by volume)</i> | <i>Notes</i> |
|-----------------------------------|------------------------------------------|--------------|-----------------------------------------------|-------------------------------------|-------------------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------------|--------------|
|                                   | <i>cloud</i>                             | <i>layer</i> |                                               |                                     |                                                       |                                               |                                                                       |              |
| Urea formaldehyde moulding powder | 460                                      |              | 0.085                                         | 80                                  | 89                                                    | 3600                                          | 9                                                                     |              |
| Urea formaldehyde resin           | 430                                      |              | 0.02                                          | 34                                  | 110                                                   | 1600                                          |                                                                       |              |
| Vanadium                          | 500                                      | 490          | 0.220                                         | 60                                  | 57                                                    | 1000                                          | 10                                                                    |              |
| Vitamin B1 mononitrate            | 380                                      | 190          | 0.035                                         | 35                                  | 120                                                   | 9000                                          | –                                                                     |              |
| Vitamin C                         | 460                                      | 280          | 0.070                                         | 60                                  | 88                                                    | 4800                                          |                                                                       |              |
| Walnut shell                      | 420                                      | 210          | 0.035                                         | 60                                  | 121                                                   | 5500                                          |                                                                       |              |
| Wax, accra                        | 260                                      |              |                                               |                                     |                                                       |                                               |                                                                       |              |
| Wax, carnauba                     | 340                                      | –            |                                               |                                     |                                                       |                                               |                                                                       |              |
| Wax, paraffin                     | 340                                      |              |                                               |                                     |                                                       |                                               |                                                                       |              |
| Wheat, flour                      | 380                                      | 360          | 0.050                                         | 50                                  | 109                                                   | 3700                                          |                                                                       |              |
| Wheat, grain dust                 | 420                                      | 290          | –                                             | –                                   | 43                                                    | –                                             |                                                                       |              |
| Wheat starch                      | 430                                      |              | 0.045                                         | 25                                  | 100                                                   | 6500                                          |                                                                       |              |
| Wood                              | 360                                      | –            |                                               | –                                   | 90                                                    | 5700                                          | 5                                                                     |              |
| Wood, bark                        | 450                                      | 250          | 0.020                                         | 60                                  | 103                                                   | 7500                                          |                                                                       |              |
| Wood, flour                       | 430                                      | –            | 0.050                                         | 20                                  | 94                                                    | 8500                                          | 7                                                                     |              |
| Wood, hard                        | 420                                      | 315          | –                                             | –                                   | 66                                                    |                                               |                                                                       |              |
| Wood, soft                        | 440                                      | 325          | –                                             | –                                   | 63                                                    | –                                             |                                                                       |              |
| Yeast                             | 520                                      | 260          | 0.050                                         | 50                                  | 123                                                   | 3500                                          |                                                                       |              |
| Zinc                              | 680                                      | 460          | 0.500                                         | 960                                 | 70                                                    | 1800                                          |                                                                       |              |
| Zinc ethylene dithio carbamate    | 480                                      | 180          |                                               |                                     | 45                                                    | 300                                           |                                                                       |              |
| Zinc stearate                     | 315                                      | Melts        | 0.020                                         | 10                                  | 80                                                    | 10 000                                        |                                                                       |              |
| Zirconium                         | 20                                       | 220          | 0.045                                         | 5                                   | 75                                                    | 11 000                                        | Ignites in carbon dioxide                                             |              |
| Zirconium hydride                 | 350                                      | 270          | 0.085                                         | 60                                  | 90                                                    | 9500                                          | 3                                                                     |              |

<sup>(1)</sup> 1 psi = 0.069 bar = 6.9 kN/m<sup>2</sup>.

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# Reactive chemicals

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From Chapter 3 all chemical reactions involve energy changes as a combination of activation energy and reaction energy. Whilst in some cases the heat of reaction is absorbed into the products and the reaction cools (endothermic reactions), most reactions evolve energy as heat (exothermic reactions), and sometimes as light and sound. When the heat liberated or absorbed cannot be accommodated by the surrounding environment hazards are presented which can result in material damage. This can arise because either the *amount* of energy (thermodynamics) or the *rate* of energy release due to the speed of reaction (reaction kinetics) is excessive. The aim therefore is to establish the thermal stability of the system and then to control the extent and rate of heat release so as to minimize risk from energetic hazards. Thousands of reactive hazards have been documented by Bretherick (see Bibliography). The present chapter provides an insight into the hazards and the basic precautions to control the risk.

Reactive chemical hazards may arise from the inherent properties of the chemicals handled, used or disposed of and/or from their admixture or processing.

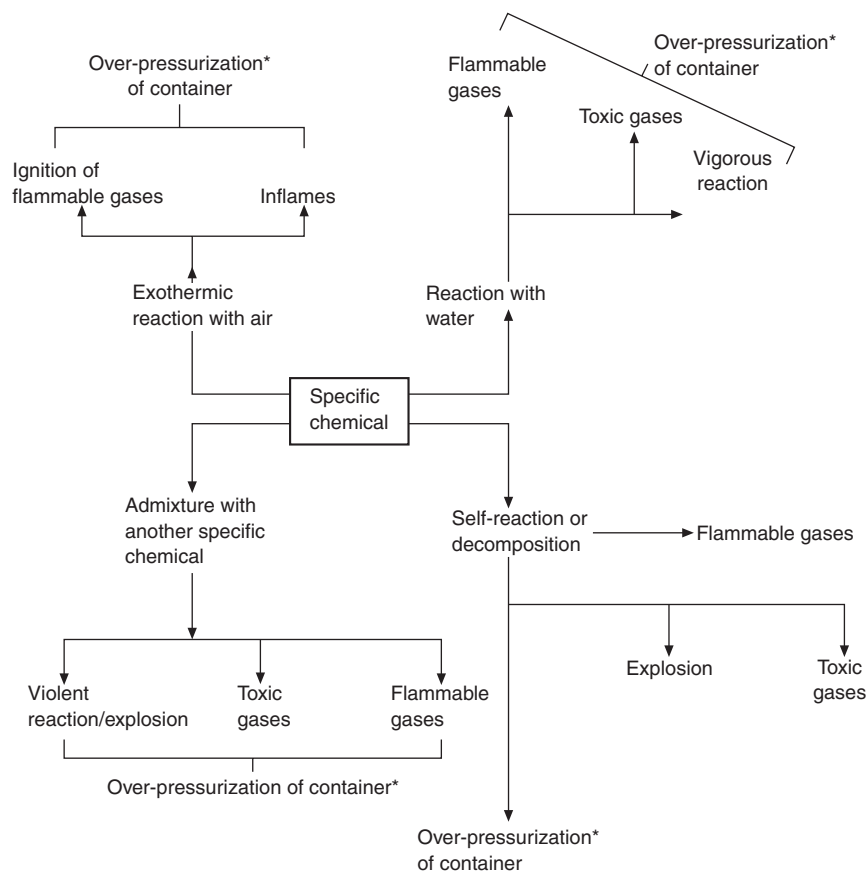
A hazard may arise with a chemical because of its tendency to decompose spontaneously or to react violently on contact with other common chemicals, as illustrated in Figure 7.1. The case of pyrophoric chemicals is summarized in Chapter 6; some dangerous reactions of compressed gases are mentioned in Chapter 9; other cases are summarized here.

However, extreme caution is necessary with mixed chemical systems since many which are thermodynamically unstable exhibit considerable kinetic stability. The kinetic barrier to stability may be overcome if traces of catalyst are present, and result in a violent reaction. The most common catalysts derive from metals, or their compounds, and the unpredictable behaviour of many reactions arises from the unwitting presence of impurities. Other catalysts include acids, bases, organic free-radical precursors, etc. Hence any system must be treated with care which

- (a) is thermodynamically unstable *or*
- (b) may contain a catalyst, or impurities which could serve as a catalyst.

## Water-sensitive chemicals

Some chemicals are ‘water-sensitive’: in contact with water they can generate flammable or toxic gases and/or undergo a vigorous reaction. Refer to Table 7.1. Such reactions can cause overpressure in sealed equipment or pipework. Selected water-sensitive chlorine compounds are given in Table 7.2. With flammable gas generation the heat of reaction may cause ignition, depending upon the compound in question, as illustrated by the list of hydrides in Table 7.3.



\*Unless venting/pressure relief is provided

**Figure 7.1** Possible reactive chemical hazards (consequences are not mutually exclusive)

### Precautions for safe handling

Store and use in such a way that accidental ingress of water, or contact with it, is avoided (roofs of storage areas should be regularly maintained to minimize leaks).

Provide covered storage, off the ground, away from sprinkler systems, safety showers, overhead water lines or condensate lines.

Keep away from water taps or sinks.

Store under a chemically-inert medium when appropriate (stocks should be checked regularly to ensure that an adequate level of inert medium is maintained).

Segregate from other flammable materials, e.g. solvents and combustibles.

Use appropriate eye/face protection, overalls and gloves.

## Toxic hazards from mixtures

Undesirable emissions of toxic gases may occur as a result of mixing relatively common chemicals. Refer to Table 7.4. Chemicals which are incompatible in this way must be brought into contact only under strictly controlled conditions.

**Table 7.1 Water-sensitive chemicals: consequences of water contact**

|                                |   |   |   |
|--------------------------------|---|---|---|
| Acetyl bromide                 |   | T |   |
| Acetyl chloride                |   | T | V |
| Acetylcholine bromide          |   | T |   |
| Aluminium (powder)             | F |   |   |
| Aluminium alkyls               | F |   | V |
| Aluminium isopropoxide         | F |   |   |
| Aluminium lithium hydride      | F |   |   |
| Aluminium selenide             |   | T |   |
| Aluminium phosphide            | F | T |   |
| Boron tribromide               |   | T |   |
| Calcium (granules)             | F |   |   |
| Calcium carbide                | F |   |   |
| Calcium hydride                | F |   |   |
| Calcium phosphide              | F | T |   |
| Chlorosulphonic acid           |   | T | V |
| Disulphur dichloride           |   | T | V |
| Ethoxides, alkaline            |   |   | V |
| Lithium (metal)                | F |   | V |
| Lithium aluminium deuteride    | F |   |   |
| Lithium aluminium dihydride    | F |   |   |
| Lithium borohydride            | F |   |   |
| Lithium hydride                | F |   |   |
| Lithium methoxide              | F |   |   |
| Magnesium (powder)             | F |   |   |
| Magnesium alkyls               | F |   |   |
| Magnesium phosphide            | F | T |   |
| Methoxides, alkaline           | F |   | V |
| Nickel sulphide                |   | T |   |
| Phosphorus pentasulphide       | F | T |   |
| Phosphorus sesquisulphide      | F | T |   |
| Phosphorus pentachloride       |   | T |   |
| Phosphorus pentabromide        |   | T |   |
| Potassium (metal)              | F |   | V |
| Potassium borohydride          | F |   |   |
| Potassium methoxide            | F |   |   |
| Silicon tetrachloride          |   | T | V |
| Sodium (metal)                 | F |   | V |
| Sodium aluminium hydride       | F |   |   |
| Sodium borohydride             | F | T |   |
| Sodium hydride                 | F |   |   |
| Sulphur dichloride             |   | T | V |
| Sulphuric acid, fuming (Oleum) |   | T | V |
| Sulphur tetrachloride          |   | T | V |
| Sulphuryl chloride             |   | T | V |
| Thionyl chloride               |   | T | V |
| Titanium tetrachloride         |   | T | V |
| Trichlorophenylsilane          |   | T |   |
| Trichlorosilane                | F |   |   |
| Zinc (powder)                  | F |   |   |
| Zinc alkyls                    |   | T | V |
| Zirconium (powder)             | F |   |   |

F Flammable gases

T Toxic products

V Vigorous reaction

**Table 7.2 Examples of reactive chlorine compounds**

| <i>Compound</i>                                       | <i>Description</i>                                                                                                                                            | <i>Reactivity</i>                                                                                                                                                                                   |
|-------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acetyl chloride<br>$\text{CH}_3\text{COCl}$           | Colourless, fuming, corrosive liquid<br>Flash point 4 C<br>When heated, emits phosgene                                                                        | Decomposes violently with water to produce heat and toxic fumes: HCl                                                                                                                                |
| Aluminium chloride (anhydrous)<br>$\text{AlCl}_3$     | Orange, yellow, grey or white powder which is a severe respiratory irritant and can cause skin/eye burns                                                      | Reacts with air moisture to form corrosive HCl gas<br>Violent reaction when a stream of water hits a large amount<br>Do not use water in vicinity                                                   |
| Benzoyl chloride<br>$\text{C}_6\text{H}_5\text{COCl}$ | Colourless, fuming, corrosive liquid with a strong odour<br>Combustible: flash point 72 C<br>Generates phosgene gas when heated                               | Reacts strongly with water or water vapour, producing heat and toxic/corrosive fumes<br>Use of water must be considered carefully                                                                   |
| Calcium hypochlorite<br>$\text{Ca}(\text{ClO})_2$     | Water soluble white crystals or powder with strong chlorine odour<br>Non-flammable but can evolve $\text{Cl}_2$ and $\text{O}_2$<br>May undergo decomposition | Water spray may be used but evolves $\text{Cl}_2$ gas freely at ordinary temperatures with moisture                                                                                                 |
| Sulphur monochloride<br>$\text{S}_2\text{Cl}_2$       | Yellowish-red oily fuming liquid with a strong odour<br>Combustible: flash point 118 C<br>Ignition temp. 233 C<br>Liquid and vapours are irritating           | Decomposes when contacted by water, to produce heat and toxic/corrosive fumes<br>Do not allow water to enter containers: reaction can be violent<br>Wash down spills with flooding amounts of water |
| Titanium tetrachloride<br>$\text{TiCl}_4$             | Colourless to light yellow fuming corrosive liquid<br>Vapour is irritating                                                                                    | Reacts vigorously with water, liberating heat and corrosive HCl gas<br>Reacts more strongly with hot water<br>Use water spray to keep exposed containers cool in fire                               |

### *Precautions*

- Provision of adequate training, instruction, and supervision.
- Prohibition on unauthorized mixing, e.g. of cleaning agents or 'wastes'.
- Correct labels.
- Segregated storage, to avoid accidental mixing.
- Dispose of wastes and 'empty' containers by different routes.
- Specific precautions against the inherent hazards of each individual chemical.

## **Reactive hazards from mixtures**

Many chemicals are 'incompatible' because a violent reaction may occur on mixing. This can, in some conditions, result in an explosion. Refer to Table 7.5.

An appraisal is needed of all chemicals which may be present, even if unintentionally (e.g. as intermediates, byproducts or wastes) and how they can react under the most extreme conditions

**Table 7.3 Variation in reactivity of hydrides with humid air or water**

| <i>Substance</i>                                            | <i>Reaction (ambient temperature)</i> |                      |
|-------------------------------------------------------------|---------------------------------------|----------------------|
|                                                             | <i>Humid air</i>                      | <i>Water</i>         |
| Aluminium borohydride ( $\text{Al}(\text{BH}_4)_3$ )        | Explosive                             | Explosive            |
| Aluminium hydride ( $\text{AlH}_3$ )                        | Slow                                  | Moderate             |
| Antimony hydride (Stibine) ( $\text{SbH}_3$ )               | Rapid                                 | Very slow            |
| Arsenic hydride (Arsine) ( $\text{AsH}_3$ )                 | Moderate                              | Very slow            |
| Barium hydride ( $\text{BaH}_2$ )                           | Rapid                                 | Rapid                |
| Beryllium borohydride ( $\text{Be}(\text{BH}_4)_2$ )        | Explosive                             | Explosive            |
| Beryllium hydride ( $\text{BeH}_2$ )                        | Slow                                  | Slow                 |
| Calcium hydride ( $\text{CaH}_2$ )                          | Moderately fast                       | Rapid                |
| Cerium hydride ( $\text{CeH}_3$ )                           | Pyrophoric                            | Slow                 |
| Caesium hydride ( $\text{CsH}$ )                            | Inflames                              | Violent              |
| Copper hydride ( $\text{CuH}$ )                             | Rapid                                 | Slow                 |
| Diborane ( $\text{B}_2\text{H}_6$ )                         | Explosive                             | Moderate             |
| Lead hydride ( $\text{PbH}_4$ )                             | Instant (unstable gas)                | —                    |
| Lithium aluminium hydride ( $\text{LiAlH}_4$ )              | Rapid                                 | Violent              |
| Lithium borohydride ( $\text{LiBH}_4$ )                     | Rapid                                 | Vigorous             |
| Lithium hydride ( $\text{LiH}$ )                            | Can ignite                            | Rapid                |
| Magnesium aluminium hydride ( $\text{Mg}(\text{AlH}_4)_2$ ) | Vigorous                              | Vigorous             |
| Magnesium borohydride ( $\text{Mg}(\text{BH}_4)_2$ )        | Very slow                             | Violent              |
| Magnesium hydride ( $\text{MgH}_2$ )                        | Known to ignite                       | Rapid                |
| Pentaborane ( $\text{B}_5\text{H}_9$ )                      | Ignites                               | Rapid                |
| Phosphorus hydride (Phosphine) ( $\text{PH}_3$ )            | Pyrophoric                            | Very slow            |
| Potassium borohydride ( $\text{KBH}_4$ )                    | Very slow                             | Very slow            |
| Potassium hydride ( $\text{KH}$ )                           | Inflames                              | Vigorous             |
| Rubidium hydride ( $\text{RbH}$ )                           | Inflames                              | Violent              |
| Silicon hydride (Silane) ( $\text{SiH}_4$ )                 | Explosive                             | Rapid                |
| Sodium aluminium hydride ( $\text{NaAlH}_4$ )               | Rapid                                 | Ignites, may explode |
| Sodium borohydride ( $\text{NaBH}_4$ )                      | Slow                                  | Slow                 |
| Sodium hydride ( $\text{NaH}$ )                             | Ignites                               | Violent              |
| Uranium hydride ( $\text{UH}_3$ )                           | Pyrophoric                            | Moderate             |

**Table 7.4 Toxic hazards from incompatible chemical mixtures**

Substances in column 1 must be stored/handled so that they cannot accidentally contact corresponding substances in column 2 because toxic materials (column 3) would be produced.

| <i>Column 1</i>     | <i>Column 2</i>                    | <i>Column 3</i>                  |
|---------------------|------------------------------------|----------------------------------|
| Arsenical materials | Any reducing agent                 | Arsine                           |
| Azides              | Acids                              | Hydrogen azide                   |
| Cyanides            | Acids                              | Hydrogen cyanide                 |
| Hypochlorites       | Acids                              | Chlorine or hypochlorous acid    |
| Nitrates            | Sulphuric acid                     | Nitrogen dioxide                 |
| Nitric acid         | Copper, brass any heavy metals     | Nitrogen dioxide (nitrous fumes) |
| Nitrites            | Acids                              | Nitrous fumes                    |
| Phosphorus          | Caustic alkalis or reducing agents | Phosphine                        |
| Selenides           | Reducing agents                    | Hydrogen selenide                |
| Sulphides           | Acids                              | Hydrogen sulphide                |
| Tellurides          | Reducing agents                    | Hydrogen telluride               |

**Table 7.5 Reactive hazards of incompatible chemicals**

Substances in column 1 must be stored/handled so that they cannot contact corresponding substances in column 2 under uncontrolled conditions, or violent reactions may occur.

| <i>Column 1</i>                                                                                                   | <i>Column 2</i>                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acetic acid                                                                                                       | Chromic acid, nitric acid, hydroxyl-containing compounds, ethylene glycol, perchloric acid, peroxides, or permanganates                                                                           |
| Acetone                                                                                                           | Concentrated nitric and sulphuric acid mixtures                                                                                                                                                   |
| Acetylene                                                                                                         | Chlorine, bromine, copper, silver, fluorine or mercury                                                                                                                                            |
| Alkali and alkaline earth metals,<br>e.g. sodium, potassium<br>lithium, magnesium, calcium,<br>powdered aluminium | Carbon dioxide, carbon tetrachloride, or other chlorinated hydrocarbons. (Also prohibit, water, foam and dry chemical on fires involving these metals – dry sand should be available)             |
| Anhydrous ammonia                                                                                                 | Mercury, chlorine, calcium hypochlorite, iodine, bromine or hydrogen fluoride                                                                                                                     |
| Ammonium nitrate                                                                                                  | Acids, metal powders, flammable liquids, chlorates, nitrites, sulphur, finely-divided organics or combustibles                                                                                    |
| Aniline                                                                                                           | Nitric acid, hydrogen peroxide                                                                                                                                                                    |
| Bromine                                                                                                           | Ammonia, acetylene, butadiene, butane or other petroleum gases, sodium carbide, turpentine, benzene, or finely-divided metals                                                                     |
| Calcium oxide                                                                                                     | Water                                                                                                                                                                                             |
| Carbon, activated                                                                                                 | Calcium hypochlorite                                                                                                                                                                              |
| Chlorates                                                                                                         | Ammonium salts, acids, metal powders, sulphur, finely-divided organics or combustibles                                                                                                            |
| Chromic acid and chromium trioxide                                                                                | Acetic acid, naphthalene, camphor, glycerol, turpentine, alcohol or other flammable liquids                                                                                                       |
| Chlorine                                                                                                          | Ammonia, acetylene, butadiene, butane or other petroleum gases, hydrogen, sodium carbide, turpentine, benzene or finely-divided metals                                                            |
| Chlorine dioxide                                                                                                  | Ammonia, methane, phosphine or hydrogen sulphide                                                                                                                                                  |
| Copper                                                                                                            | Acetylene, hydrogen peroxide                                                                                                                                                                      |
| Fluorine                                                                                                          | Isolate from everything                                                                                                                                                                           |
| Hydrazine                                                                                                         | Hydrogen peroxide, nitric acid, or any other oxidant                                                                                                                                              |
| Hydrocarbons (benzene, butane, propane, gasoline, turpentine, etc.)                                               | Fluorine, chlorine, bromine, chromic acid, peroxides                                                                                                                                              |
| Hydrocyanic acid                                                                                                  | Nitric acid, alkalis                                                                                                                                                                              |
| Hydrofluoric acid, anhydrous (hydrogen fluoride)                                                                  | Ammonia, aqueous or anhydrous                                                                                                                                                                     |
| Hydrogen peroxide                                                                                                 | Copper, chromium, iron, most metals or their salts, any flammable liquid, combustible materials, aniline, nitromethane                                                                            |
| Hydrogen sulphide                                                                                                 | Fuming nitric acid, oxidizing gases                                                                                                                                                               |
| Iodine                                                                                                            | Acetylene, ammonia (anhydrous or aqueous)                                                                                                                                                         |
| Mercury                                                                                                           | Acetylene, fulminic acid (produced in ethanol – nitric acid mixtures), ammonia                                                                                                                    |
| Nitric acid (conc)                                                                                                | Acetic acid, acetone, alcohol, aniline, chromic acid, hydrocyanic acid, hydrogen sulphide, flammable liquids, flammable gases, or nitratable substances, paper, cardboard or rags                 |
| Nitroparaffins                                                                                                    | Inorganic bases, amines                                                                                                                                                                           |
| Oxalic acid                                                                                                       | Silver, mercury                                                                                                                                                                                   |
| Oxygen                                                                                                            | Oils, grease, hydrogen, flammable liquids, solids or gases                                                                                                                                        |
| Perchloric acid                                                                                                   | Acetic anhydride, bismuth and its alloys, alcohol, paper, wood, grease, oils                                                                                                                      |
| Peroxides, organic                                                                                                | Acids (organic or mineral), avoid friction, store cold                                                                                                                                            |
| Phosphorus (white)                                                                                                | Air, oxygen                                                                                                                                                                                       |
| Potassium chlorate                                                                                                | Acids (see also chlorates)                                                                                                                                                                        |
| Potassium perchlorate                                                                                             | Acids (see also perchloric acid)                                                                                                                                                                  |
| Potassium permanganate                                                                                            | Glycerol, ethylene glycol, benzaldehyde, sulphuric acid                                                                                                                                           |
| Silver                                                                                                            | Acetylene, oxalic acid, tartaric acid, fulminic acid (produced in ethanol–nitric acid mixtures), ammonium compounds                                                                               |
| Sodium                                                                                                            | See alkali metals (above)                                                                                                                                                                         |
| Sodium nitrite                                                                                                    | Ammonium nitrate and other ammonium salts                                                                                                                                                         |
| Sodium peroxide                                                                                                   | Any oxidizable substance, such as ethanol, methanol, glacial acetic acid, acetic anhydride, benzaldehyde, carbon disulphide, glycerol, ethylene glycol, ethyl acetate, methyl acetate or furfural |
| Sulphuric acid                                                                                                    | Chlorates, perchlorates, permanganates                                                                                                                                                            |



(e.g. concentration, agitation, temperature, pressure) likely to arise. Sometimes special testing is required.

For reactions with air or water, refer to pyrophoric chemicals (Chapter 6).

In acid-base reactions, the heat of neutralization of aqueous acids and bases can be sufficient to cause 'spitting' from containers when the concentrated reagents interact. This is also encountered when concentrated sulphuric acid is diluted (refer to Table 7.1); the acid should always be added cautiously to water and not vice versa. Eye and skin protection is obligatory when using such reagents.

## Oxidizing agents

Oxidizing agents, although not normally spontaneously flammable, often represent a source of oxygen that can support combustion. They will react readily in contact with reducing reagents. Hence an oxidizing agent will invariably accelerate the rate of burning of a combustible material. In finely divided state such mixtures may react explosively.

Some common oxidizing agents are classified according to stability in Table 7.6.

**Table 7.6 Common oxidizing agents classified according to stability**

| <i>Classification</i>                                                                                                                                                               | <i>Example</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Relatively stable</b><br>Increase the burning rate of combustible materials<br>Form highly flammable or explosive mixtures with finely divided combustible materials             | Aluminium nitrate<br>Ammonium persulphate<br>Barium nitrate/peroxide<br>Calcium nitrate/peroxide<br>Cupric nitrate<br>Hydrogen peroxide solutions (8–27.5% by weight)<br>Lead nitrate<br>Lithium peroxide/hypochlorite<br>Magnesium nitrate/perchlorate<br>Nickel nitrate<br>Nitric acid (concentrations $\leq 70\%$ )<br>Potassium dichromate/nitrate/persulphate<br>Silver nitrate<br>Sodium dichromate/nitrate/nitrite/perborate/persulphate/chlorite ( $\leq 40\%$ by weight)<br>Strontium nitrate/peroxide<br>Zinc peroxide |
| <b>Moderately unstable/reactive</b><br>Undergo vigorous decomposition on heating<br>Explode when heated in a sealed container<br>Cause spontaneous heating of combustible materials | Ammonium dichromate<br>Barium chlorate<br>Calcium chlorate/hypochlorite<br>Chromium trioxide (chromic acid)<br>Hydrogen peroxide solutions (27.5–91% by weight)<br>Nitric acid (concentrations $> 70\%$ )<br>Potassium bromide/chlorate/permanganate/peroxide<br>Sodium chlorate/permanganate/peroxide/chlorite ( $> 40\%$ by weight)<br>Strontium chlorate                                                                                                                                                                      |
| <b>Unstable</b><br>Explode when catalysed or exposed to heat, shock or friction<br>Liberate oxygen at room temperatures                                                             | Ammonium chlorate/perchlorate/permanganate<br>Benzoyl peroxide<br>Guanidine nitrate<br>Mercury chlorate<br>Methyl ethyl ketone peroxide<br>Potassium superoxide                                                                                                                                                                                                                                                                                                                                                                  |

*Safe handling*

Handle and store the minimum quantities practicable for the process or experiments in progress. Segregate the materials from other chemicals, particularly reducing agents, paper, straw, cloth or materials of low flash point.

Handle in the most dilute form possible in clearly designated areas, away from potential ignition sources.

Provide and use appropriate eye/face protection, overalls and gloves.

Hazards arising from the oxidation of organic compounds are greater when the reactants are volatile, or present as a dust or an aerosol. Liquid oxygen and various concentrated acids, e.g. nitric, sulphuric or perchloric acid, and chromic acid are strong oxidizing agents. The use of perchloric acid or perchlorates has resulted in numerous explosions; their use should be avoided when possible (refer to Table 7.5).

## Explosive chemicals

Explosions involving flammable gases, vapours and dusts are discussed in Chapter 6. In addition, certain chemicals may explode as a result of violent self-reaction or decomposition when subjected to mechanical shock, friction, heat, light or catalytic contaminants. Substances containing the atomic groupings listed in Table 7.7 are thermodynamically unstable, or explosive. They include acetylides and acetylenic compounds, particular nitrogen compounds, e.g. azides and fulminates, peroxy compounds and vinyl compounds. These unstable moieties can be classified further as in Table 7.8 for peroxides. Table 7.9 lists a selection of potentially-explosive compounds.

More specific definitions of 'explosives' appear in legislation, e.g. in the UK under the Explosives Act 1875 as amended, which covers:

High explosives which detonate to produce shock waves. Materials which are easily detonated by mechanical or electrical stimuli are termed 'primary explosives'. Those requiring an impinging shock wave to initiate them are 'secondary explosives'.

Pyrotechnics which burn to produce heat, smoke, light and/or noise.

Propellants which burn to produce heat and gas as a means of pressurizing pistons, start engines, propel projectiles and rockets.

The precautions with any particular explosive depends on the hazard. In the UK explosives are classified as: 1 – Gunpowder; 2 – Nitrate mixture; 3 – Nitro compound; 4 – Chlorate mixture; 5 – Fulminate; 6 – Ammunition and 7 – Fireworks.

For the purposes of safety distances in connection with the issue of licences for factories and magazines, explosives have been categorized as: X – fire or slight explosion risks or both, with only local effect; Y – mass fire risks or moderate explosion risk, but not mass explosion risk; Z – mass explosion risk with serious missile effect; ZZ – mass explosion risk with minor missile effect.

Hazards can be illustrated by reference to Table 7.10 (showing the explosive effects of small quantities of high explosives in a 6 m × 6 m single-storey building) and to Figure 7.2 (relating the size of fireball to quantity of burning pyrotechnic, high explosive or propellant). With pyrotechnics the hazard is related to the violence with which the chemical burns. One scheme used to classify pyrotechnics is given in Table 7.11. This is used to restrict quantities in use/storage and for

Table 7.7 Atomic groupings characterizing explosive compounds

| Bond groupings                                                                                                                                                                  | Class                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| $-\text{C}\equiv\text{C}-$<br>$-\text{C}\equiv\text{C}-\text{Metal}$<br>$-\text{C}\equiv\text{C}-\text{X}$<br>$\begin{array}{c} \text{N}=\text{N} \\   \\ \text{C} \end{array}$ | Acetylenic Compounds<br>Metal Acetylides<br>Haloacetylene derivatives<br>Diazirines |
| $>\text{CN}_2$                                                                                                                                                                  | Diazo Compounds                                                                     |
| $>\text{C}-\text{N}=\text{O}$<br>$>\text{C}-\text{NO}_2$                                                                                                                        | Nitroso Compounds<br>Nitroalkanes, C-Nitro and Polynitroaryl compounds              |
| $\begin{array}{c} \text{NO}_2 \\   \\ \text{C} \\   \\ \text{NO}_2 \end{array}$                                                                                                 | Polynitroalkyl compounds                                                            |
| $>\text{C}-\text{O}-\text{N}=\text{O}$<br>$>\text{C}-\text{O}-\text{NO}_2$                                                                                                      | Acyl or alkyl nitrites<br>Acyl or alkyl nitrates                                    |
| $\begin{array}{c} \diagup \text{C} - \text{C} \diagdown \\   \quad \quad   \\ \text{O} \end{array}$                                                                             | 1,2-Epoxides                                                                        |
| $>\text{C}=\text{N}-\text{O}-\text{Metal}$                                                                                                                                      | Metal Fulminates or aci-nitro salts                                                 |
| $\begin{array}{c} \text{NO}_2 \\   \\ -\text{C}-\text{F} \\   \\ \text{NO}_2 \end{array}$                                                                                       | Fluorodinitromethyl compounds                                                       |
| $>\text{N}-\text{Metal}$                                                                                                                                                        | N-Metal Derivatives                                                                 |
| $>\text{N}-\text{N}=\text{O}$                                                                                                                                                   | N-Nitroso Compounds                                                                 |
| $>\text{N}-\text{NO}_2$                                                                                                                                                         | N-Nitro Compounds                                                                   |
| $>\text{C}-\text{N}=\text{N}-\text{C} \diagdown$                                                                                                                                | Azo Compounds                                                                       |
| $>\text{C}-\text{N}=\text{N}-\text{O}-\text{C} \diagdown$                                                                                                                       | Arenediazoates                                                                      |
| $>\text{C}-\text{N}=\text{N}-\text{S}-\text{C} \diagdown$                                                                                                                       | Arenediazo aryl sulphides                                                           |
| $>\text{C}-\text{N}=\text{N}-\text{O}-\text{N}=\text{N}-\text{C} \diagdown$                                                                                                     | Bis-arenediazo oxides                                                               |
| $>\text{C}-\text{N}=\text{N}-\text{S}-\text{N}=\text{N}-\text{C} \diagdown$                                                                                                     | Bis-arenediazo sulphides                                                            |
| $>\text{C}-\text{N}=\text{N}-\text{N}-\text{C} \diagdown$<br>$\quad \quad \quad  $<br>$\quad \quad \quad \text{R}$                                                              | Triazenes (R=H, -CN, -OH, -NO)                                                      |
| $-\text{N}=\text{N}-\text{N}=\text{N}-$                                                                                                                                         | High-nitrogen compounds tetrazoles                                                  |
| $>\text{C}-\text{O}-\text{O}-\text{H}$<br>$>\text{C}-\text{CO}-\text{OOH}$                                                                                                      | Alkylhydroperoxides<br>Peroxyacids                                                  |
| $>\text{C}-\text{O}-\text{O}-\text{C} \diagdown$<br>$>\text{C}-\text{CO}-\text{OOR}$                                                                                            | Peroxides (cyclic, diacyl, dialkyl)<br>Peroxyesters                                 |
| $-\text{O}-\text{O}-\text{Metal}$                                                                                                                                               | Metal peroxides, peroxyacid salts                                                   |
| $-\text{O}-\text{O}-\text{Non-metal}$                                                                                                                                           | Peroxoacids                                                                         |
| $\text{N} \rightarrow \text{Cr}-\text{O}_2$                                                                                                                                     | Aminechromium peroxo-complexes                                                      |
| $-\text{N}_3$                                                                                                                                                                   | Azides (acyl, halogen, non-metal, organic)                                          |
| $\begin{array}{c} \text{C} \\   \\ \text{N}_2^+ \text{O}^- \end{array}$                                                                                                         | Arenediazoniumolates                                                                |
| $>\text{C}-\text{N}_2^+ \text{S}^-$                                                                                                                                             | Diazonium sulphides and derivatives, 'xanthates'                                    |
| $\text{N}^+ - \text{HZ}^-$                                                                                                                                                      | Hydrazinium salts, oxosalts of nitrogenous bases                                    |
| $-\text{N}^+ - \text{OH Z}^-$                                                                                                                                                   | Hydroxylammonium salts                                                              |

Table 7.7 Cont'd

| Bond groupings                        | Class                                                                                                     |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------|
| $\text{>C} - \text{N}_2^+ \text{Z}^-$ | Diazonium carboxylates or salts                                                                           |
| $(\text{N-Metal})^+ \text{Z}^-$       | Aminemetal oxosalts                                                                                       |
| Ar-Metal-X<br>X-Ar-Metal              | Halo-Arylmetals                                                                                           |
| N-X                                   | Halogen Azides, N-Halogen compounds, N-Haloimides                                                         |
| $-\text{NF}_2$                        | Difluoroamino compounds                                                                                   |
| $-\text{O-X}$                         | Alkyl perchlorates, Chlorite salts, Halogen oxides,<br>Hypohalites, Perchloric acid, Perchloryl Compounds |

Table 7.8 Classification of organic peroxides

| Peroxide class                                                   | General structures or characteristic group                                                                                                                                                                                                                                                                                                                          |
|------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hydroperoxides                                                   | ROOH<br>$\text{R}_m\text{Q}(\text{OOH})_n$<br>(Q = metal or metalloid)                                                                                                                                                                                                                                                                                              |
| $\alpha$ -Oxy- and $\alpha$ -peroxy-hydroperoxides and peroxides | contain the grouping:<br>$\begin{array}{c} \text{OO}^- \\   \\ \text{C} \\   \\ \text{O}^- \end{array}$                                                                                                                                                                                                                                                             |
| Peroxides                                                        | ROOR'<br>$\text{R}_m\text{Q}(\text{OOR})_n$<br>$\text{R}_m\text{QOOQR}_n$                                                                                                                                                                                                                                                                                           |
| Peroxyacids                                                      | $\text{R}(\text{CO}_3\text{H})_n$<br>$\text{RSO}_2\text{OOH}$                                                                                                                                                                                                                                                                                                       |
| Diacyl peroxides                                                 | $\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{RCOOCR}' \\ \text{O} \quad \text{O} \\    \quad    \\ \text{ROCOOCR} \\ \text{O} \quad \text{O} \\    \quad    \\ \text{RSOOCR} \\ \text{O} \\    \\ \text{O} \\ \text{O} \quad \text{O} \\    \quad    \\ \text{RSOOSR} \\ \text{O} \quad \text{O} \\    \quad    \\ \text{RCOOCR}' \end{array}$ |
| Peroxyesters                                                     | $\begin{array}{c} \text{R}(\text{CO}_3\text{R}')_n \\ \text{R}'(\text{O}_3\text{CR})_2 \\ \text{O} \\    \\ \text{ROCOOR}' \\ \text{O} \\    \\ \text{ROOCOOR} \\ \text{O} \\    \\ \text{>NCOOR} \\ \text{O} \\    \\ \text{RSOOR}' \\ \text{O} \\    \\ \text{O} \end{array}$                                                                                     |

Table 7.9 Selected potentially explosive compounds

**(a) Peroxy compounds***(i) Organic peroxy compounds*

Acetyl cyclohexane-sulphonyl peroxide (70%)  
 Acetyl cyclohexane-sulphonyl peroxide (28% phthalate solution)  
*o*-Azidobenzoyl peroxide  
*t*-Butyl mono permaleate (95% dry)  
*t*-Butyl peracetate (70%)  
*t*-Butyl peroctanoate  
*t*-Butyl perpivalate (75% hydrocarbon solution)  
*t*-Butyl peroxy isobutyrate  
 Bis-hexahydrobenzoyl peroxide  
 Bis-monofluorocarbonyl peroxide  
 Bis-benzenesulphonyl peroxide  
 Bis-hydroxymethyl peroxide  
 Bis (1-hydroxycyclohexyl) peroxide  
 2,2-Bis (*t*-butylperoxy) butane  
 2,2-Bis-hydroperoxy diisopropylidene peroxide  
 Barium methyl peroxide  
 Benzene triozone  
 Cyclohexanone peroxide (95% dry)  
 Diacetyl peroxide  
 Di-*n*-butyl perdicarbonate (25% hydrocarbon solution)  
 2:4-Dichlorobenzoyl peroxide (50% phthalate solution)  
 Dicaproyl peroxide  
 Dicyclohexyl perdicarbonate  
 Di-2-ethylhexyl perdicarbonate (40% hydrocarbon solution)  
 Dimethyl peroxide  
 Diethyl peroxide  
 Di-*t*-butyl-di-peroxyphthalate  
 Difuroyl peroxide  
 Dibenzoyl peroxide  
 Dimeric ethylidene peroxide  
 Dimeric acetone peroxide  
 Dimeric cyclohexanone peroxide  
 Diozonide of phorone  
 Dimethyl ketone peroxide  
 Ethyl hydroperoxide  
 Ethylene ozonide  
 Hydroxymethyl methyl peroxide  
 Hydroxymethyl hydroperoxide  
 1-Hydroxyethyl ethyl peroxide  
 1-Hydroperoxy-1-acetoxycyclodecan-6-one  
 Isopropyl percarbonate  
 Isopropyl hydroperoxide  
 Methyl ethyl ketone peroxide  
 Methyl hydroperoxide  
 Methyl ethyl peroxide  
 Monoperoxy succinic acid  
 Nonanoyl peroxide (75% hydrocarbon solution)  
 1-Naphthoyl peroxide  
 Oxalic acid ester of *t*-butyl hydroperoxide  
 Ozonide of maleic anhydride  
 Phenylhydrazone hydroperoxide  
 Polymeric butadiene peroxide  
 Polymeric isoprene peroxide

Polymeric dimethylbutadiene peroxide  
 Polymeric peroxides of methacrylic acid esters and styrene  
 Polymeric peroxide of asymmetrical diphenylethylene  
 Peroxyformic acid  
 Peroxyacetic acid  
 Peroxybenzoic acid  
 Peroxycaproic acid  
 Polymeric ethylidene peroxide  
 Sodium peracetate  
 Succinic acid peroxide (95% dry)  
 Trimeric acetone peroxide  
 Trimeric propylidene peroxide  
 Tetraacetate of 1,1,6,6-tetrahydroperoxycyclodecane

*(ii) Inorganic peroxy compounds**Peroxides*

Hydrogen peroxide (>30%)  
 Mercury peroxide

*Peroxyacids*

Peroxydisulphuric acid  
 Peroxynitric acid  
 Peroxy ditungstic acid

*Peroxyacid salts*

Sodium peroxyborate (anhydrous)  
 Sodium triperoxychromate  
 Sodium peroxymolybdate  
 Sodium peroxynickelate  
 Sodium diperoxytungstate  
 Potassium peroxyferrate  
 Potassium peroxynickelate  
 Potassium hyperoxytungstate  
 Potassium peroxy pyrovanadate  
 Calcium diperoxydisulphate  
 Calcium peroxychromate  
 Zinc tetraaminoperoxydisulphate  
 Ammonium peroxyborate  
 Ammonium peroxymanganate  
 Ammonium peroxychromate

*Superoxides*

Potassium superoxide  
 Ozone (liquid >30%)  
 Potassium ozonide  
 Caesium ozonide  
 Ammonium ozonide

*Inorganic peracids and their salts (common examples which are particularly hazardous)*

Ammonium perchlorate  
 Ammonium persulphate  
 Ammonium pernitrate  
 Perchloric acid (>73%)  
 Performic acid  
 Silver perchlorate  
 Tropylium perchlorate

Table 7.9 Cont'd

**(b) Halo-acetylenes and acetylides**

Lithium bromoacetylide  
 Dibromoacetylene  
 Lithium chloroacetylide  
 Sodium chloroacetylide  
 Dichloroacetylene  
 Bromoacetylene  
 Chloroacetylene  
 Fluoroacetylene  
 Diiodoacetylene  
 Silver trifluoromethylacetylide  
 Chlorocyanoacetylene  
 Lithium trifluoromethylacetylide  
 3,3,3-Trifluoropropyne  
 1-Bromo-2-propyne  
 1-Chloro-2-propyne  
 1-Iodo-1,3-butadiyne  
 1,4-Dichloro-2-butyne  
 1-Iodo-3-penten-1-yne  
 1,6-Dichloro-2,4-hexadiyne  
 2,4-Hexadiynylene bischlorosulphite  
 Tetra (chloroethynyl) silane  
 2,4-Hexadiynylene bischloroformate  
 1-Iodo-3-Phenyl-2-propyne  
 1-Bromo-1,2-cyclotridecadien-4,8,10-triyne

**(c) Metal acetylides**

Disilver acetylide  
 Silver acetylide-silver nitrate  
 Digold(I) acetylide  
 Barium acetylide  
 Calcium acetylide (carbide)  
 Dicaesium acetylide  
 Copper(II) acetylide  
 Dicopper(I) acetylide  
 Silver acetylide  
 Caesium acetylide  
 Potassium acetylide  
 Lithium acetylide  
 Sodium acetylide  
 Rubidium acetylide  
 Lithium acetylide-ammonia  
 Dipotassium acetylide  
 Dilithium acetylide  
 Disodium acetylide  
 Dirubidium acetylide  
 Strontium acetylide  
 Silver trifluoromethylacetylide  
 Sodium methoxyacetylide  
 Sodium ethoxyacetylide  
 1,3-Pentadiyn-1-ysilver  
 1,3-Pentadiyn-1-ylcopper  
 Dimethyl-1-propynylthallium  
 Triethynylaluminium  
 Triethynylantimony  
 Bis(Dimethylthallium) acetylide  
 Tetraethynylgermanium  
 Tetraethynyltin  
 Sodium phenylacetylide

3-Buten-1-ynyl-diethylaluminium  
 Dimethyl-phenylethynylthallium  
 3-Buten-1-ynyltriethyllead  
 3-Methyl-3-buten-1-ynyltriethyllead  
 3-Buten-1-ynyl-diisobutylaluminium  
 Bis(Triethyltin) acetylene

**(d) Metal azides**

Aluminium triazide  
 Barium diazide  
 Boron triazide  
 Cadmium diazide  
 Calcium diazide  
 Chromyl azide  
 Copper(I) azide  
 Copper(II) azide  
 Lead(II) azide  
 Lead(IV) azide  
 Lithium azide  
 Lithium boroazide  
 Mercury(I) azide  
 Mercury(II) azide  
 Potassium azide  
 Silicon tetraazide  
 Silver azide

**(e) Metal azide halides**

Chromyl azide chloride  
 Molybdenum azide pentachloride  
 Molybdenum azide tetrachloride  
 Silver azide chloride  
 Tin azide trichloride  
 Titanium azide trichloride  
 Tungsten azide pentabromide  
 Uranium azide pentachloride  
 Vanadium azide dichloride  
 Vanadyl azide tetrachloride

**(f) Diazo compounds**

1,1-Benzoylphenyldiazomethane  
 2-Butan-1-yl diazoacetate  
 t-Butyl diazoacetate  
 t-Butyl-2-diazoacetoacetate  
 Diazoacetoneitrile  
 2-Diazocyclohexanone  
 Diazocyclopentadiene  
 1-Diazoindine  
 Diazomethane (The precursor of this compound  
 (N-Methyl-N-nitroso-toluene-4-sulphonamide)  
 is available commercially)  
 Diazomethylthallium  
 Diazomethylsodium  
 Dicyanodiazomethane  
 Dinitrodiazomethane  
 Isodiazomethane  
 Methyl diazoacetate

**(g) Metal fulminates**

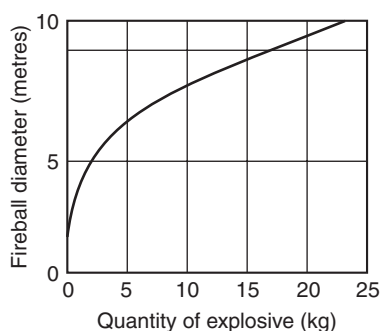
Cadmium fulminate

Table 7.9 Cont'd

|                                                     |                                                                |
|-----------------------------------------------------|----------------------------------------------------------------|
| Copper fulminate                                    | Potassium-3,5-dinitro-2(1-tetrazenyl) phenolate                |
| Dimethylthallium fulminate                          | Potassium trinitromethanide ('Nitroform' salt)                 |
| Diphenylthallium fulminate                          | Sodium 5-dinitromethyltetrazolide                              |
| Mercury(II) methylnitrolate                         | Tetranitromethane                                              |
| Mercury(II) formhydroxamate                         | Trichloronitromethane (chloropicrin)                           |
| Mercury(II) fulminate                               | 2,2,4-Trimethyldecahydroquinoline picrate                      |
| Silver fulminate                                    | Trinitroacetoneitrile                                          |
| Sodium fulminate                                    | 1,3,5-Trinitrobenzene                                          |
| Thallium fulminate                                  | 2,4,6-Trinitrobenzenesulphonic acid<br>(picryl sulphonic acid) |
| <b>(h) Nitro compounds</b>                          | Trinitrobenzoic acid                                           |
| <b>(i) C-Nitro compounds</b>                        | 2,2,2-Trinitroethanol                                          |
| 4-Chloro-2,6,-dinitroaniline                        | Trinitromethane                                                |
| 2-Chloro-3,5-dinitropyridine                        | 2,4,6-Trinitrophenol (picric acid)                             |
| Chloronitromethane                                  | 2,4,6-Trinitroresorcinol                                       |
| 1-Chloro-2,4,6-trinitrobenzene (picryl chloride)    | 2,4,6-Trinitrotoluene (TNT)                                    |
| Dinitroacetoneitrile                                | 2,4,6-Trinitro- <i>m</i> -xylene                               |
| 2,4-Dinitroaniline                                  |                                                                |
| Dinitroazomethane                                   | <b>(ii) N-Nitro compounds</b>                                  |
| 1,2-Dinitrobenzene                                  | 1-Amino-3-nitroguanidine                                       |
| 1,3-Dinitrobenzene                                  | Azo-N-nitroformamidine                                         |
| 1,4-Dinitrobenzene                                  | 1,2-Bis(difluoroamino)N-nitroethylamine                        |
| 2,4-Dinitrobenzenesulphenyl chloride                | N,N' Diacetyl-N,N'-dinitro-1,2-diaminoethane                   |
| 3,5-Dinitrobenzoic acid                             | N,N' Dinitro-1,2-diaminoethane                                 |
| 3,5-Dinitrobenzoyl chloride                         | N,N' Dinitro-N-methyl-1,2-diaminoethane                        |
| 2,6-Dinitrobenzyl bromide                           | 1-methyl-3-nitro-1-nitrosoguanidine                            |
| 1,1-Dinitro-3-butene                                | Nitric amide (nitramide)                                       |
| 2,3-Dinitro-2-butene                                | 1-Nitro-3(2,4-dinitrophenyl) urea                              |
| 3,5-Dinitrochlorobenzene                            | Nitroguanidine                                                 |
| 2,4-Dinitro-1-fluorobenzene                         | N-Nitromethylamine                                             |
| 2,6-Dinitro-4-perchlorylphenol                      | Nitrourea                                                      |
| 2,5-Dinitrophenol                                   | N,2,4,6-Tetranitro-N-methylaniline (tetryl)                    |
| 2,4-Dinitrophenylacetyl chloride                    | 1,3,5,7-Tetranitroperhydro-1,3,5,7-tetrazocine                 |
| 2,4-Dinitrophenylhydrazine                          |                                                                |
| 2,4-Dinitrophenylhydrazinium perchlorate            | <b>(iii) Ammonium nitrate</b>                                  |
| 2,7-Dinitro-9-phenylphenanthridine                  |                                                                |
| 2,4-Dinitrotoluene                                  | <b>(i) Reactive vinyl monomers</b>                             |
| 1-Fluoro-2,4-dinitrobenzene                         | Acrylic acid                                                   |
| 4-Hydroxy-3,5-dinitrobenzene arsonic acid           | Acrylonitrile                                                  |
| 1-Nitrobutane                                       | <i>n</i> -Butyl acrylate                                       |
| 2-Nitrobutane                                       | <i>n</i> -Butyl methacrylate                                   |
| 1-Nitro-3-butene                                    | 4-Chlorostyrene                                                |
| Nitrocellulose                                      | Divinyl benzene                                                |
| 1-Nitro-3 (2,4-dinitrophenyl) urea                  | Dodecyl methacrylate                                           |
| Nitroethane                                         | Ethyl acrylate                                                 |
| 2-Nitroethanol                                      | Ethylene dimethacrylate                                        |
| Nitroglycerine                                      | 2-Hydroxypropyl methacrylate                                   |
| Nitromethane                                        | Methyl acrylate                                                |
| 1-Nitropropane                                      | Methyl methacrylate                                            |
| 2-Nitropropane                                      | $\alpha$ -Methyl styrene                                       |
| 5-Nitrotetrazole                                    | Methyl vinyl ether                                             |
| Picric acid (2,4,6-trinitrophenol)                  | Styrene                                                        |
| Potassium-4,6-dinitrobenzofuroxan hydroxide complex | Vinyl acetate                                                  |
|                                                     | Vinyl bromide                                                  |

**Table 7.10 Explosive effects of small quantities of high explosive in a 6 m × 6 m room**

| <i>Quantity of explosive</i> | <i>Effect</i>                                                                                                            |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| 1 g                          | Serious injury to a person holding the explosive                                                                         |
| 10 g                         | Very serious injury to a person close to the explosive                                                                   |
| 100 g                        | 1% of persons at a distance of 1.5 m are also liable to ear-drum rupture                                                 |
|                              | 50% of windows in room likely to be blown out                                                                            |
|                              | 1% ear-drum rupture at 3.5 m                                                                                             |
| 500 g                        | 50% ear-drum rupture at 1.5 m                                                                                            |
|                              | Almost certain death of persons in very close proximity (e.g. holding the explosive)                                     |
|                              | Complete structural collapse of brick-built building probable                                                            |
|                              | Probable survival of steel or concrete-framed building                                                                   |
|                              | Almost certain death of persons very close to blast                                                                      |
|                              | Persons close to blast seriously injured by lung and hearing damage, fragmentation effects, and from being thrown bodily |
|                              | Ear-drum rupture of almost all persons within the room                                                                   |

**Figure 7.2** *Diameter of fireball versus quantity of explosive*

selection of the appropriate safety precautions. Propellant hazards are akin to those for pyrotechnics except that confinement can lead to detonation.

### *Precautions*

Expert advice is required before handling any of these materials, many of which are governed by legislation regulating, e.g., licensing of premises, use, storage, transportation, import/export, sale, labelling, disposal. Some general considerations are given in Table 7.12. Table 7.13 summarizes basic precautions for work on a laboratory scale.

Disposal of explosive waste and the repair or dismantling of contaminated plant need extreme care. Table 7.14 provides guidance on techniques for disposal of the more commonly encountered explosives by experts at proper disposal sites. Collection of the waste should be in well labelled, distinctive, specially designed containers. Cleaning and decontamination of plant comprises removal of gross contamination under wet or solvent conditions using tools made of soft material, final cleaning with solvent or chemical reagent, and finally ‘proving’ of the equipment by heating to temperatures exceeding those for decomposition of the contaminant. Repair work should be the subject of a permit-to-work system (Chapter 13); it should be assumed that explosives may have penetrated threads, joints and other crevices and bolts, flanges etc. These should be thoroughly decontaminated prior to dismantling. Operatives should be suitably trained and protected.



**Table 7.11 Classification of pyrotechnics**

| <i>Composition</i>                                                                                                                                                                                                 | <i>Behaviour</i>         | <i>Artefacts</i>                                                                                                                                                                                                           | <i>Characteristics</i>                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| <b>Group 1</b>                                                                                                                                                                                                     |                          |                                                                                                                                                                                                                            |                                                 |
| Chlorate and metal perchlorate report or whistling compositions<br>Dry non-gelatinized cellulose nitrates<br>Barium peroxide/zirconium compositions                                                                | Burn very violently      | Flash shells (maroons)<br>Casings containing flash compositions<br>Sealed hail-preventing rockets                                                                                                                          | Mass explosion risk                             |
| <b>Group 2</b>                                                                                                                                                                                                     |                          |                                                                                                                                                                                                                            |                                                 |
| Nitrate/metal/sulphur compositions<br>Compositions with >65% chlorate<br>Black powder<br>Nitrate/boron compositions                                                                                                | Burn violently           | Large firework shells<br>Fuse unprotected signal flares<br>Non-pressed report bullets (bird scarers)<br>Report cartridges (unpacked)<br>Black matches (uncovered)                                                          | Accelerating single-item explosions             |
| <b>Group 3</b>                                                                                                                                                                                                     |                          |                                                                                                                                                                                                                            |                                                 |
| Nitrate/metal compositions without sulphur<br>Compositions with <35–65% chlorate<br>Compositions with black powder<br>Lead oxide/silicon with >60% lead oxides<br>Perchlorate/metal compositions other than report | Burn fast                | Large firework shells<br>Fuse protected signal flares<br>Pressed report cartridges in primary packagings<br>Quickmatches in transport packagings<br>Waterfalls; Silver wheels;<br>Volcanoes<br>Black powder delays         | Burn very violently with single-item explosions |
| <b>Group 4</b>                                                                                                                                                                                                     |                          |                                                                                                                                                                                                                            |                                                 |
| Coloured smoke compositions<br>White smoke compositions (except those in Group 5)<br>Compositions with <35% chlorate<br>Thermite compositions<br>Aluminium/phosphorus pesticide compositions                       | Low/medium speed burning | Large firework shells without flash compositions in transport packagings<br>Signal ammunition without flash compositions, ≤40 g of composition<br>Small fireworks, fuse protected (except volcanoes and silver wheels)     | Single-item ignitions/explosions                |
| <b>Group 5</b>                                                                                                                                                                                                     |                          |                                                                                                                                                                                                                            |                                                 |
| Slow burning/heating compositions<br>White smoke compositions based on hexachloroethane with zinc, zinc oxide and <5% aluminium or <10% calcium silicon                                                            | Burn slowly              | Small fireworks in primary packagings<br>Signal ammunition in transport packaging<br>Delays without black powder<br>Coloured smoke devices<br>Sealed table bombs<br>White smoke devices unpacked (see Group 5 composition) | Slow single-item ignitions/explosions           |

**Table 7.12 General considerations for work with explosive chemicals**


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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Consult with experts on the hazards and on technical, administrative and legal requirements.                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| The chance of accidental initiation is related to the energy imparted to the substance and the sensitivity of the compound.                                                                                                                                                                                                                                                                                                                                                                                                             |
| Hence the sensitivity of compounds should be established (e.g. Table 7.15) before devising appropriate control measures.                                                                                                                                                                                                                                                                                                                                                                                                                |
| (Many sensitive explosives have ignition energies of 1–45 mJ, while some very sensitive materials have ignition energies <1 mJ.)                                                                                                                                                                                                                                                                                                                                                                                                        |
| Depending on scale, specially designed facilities may be required, remote from other buildings, accessways or populated areas. Remote handling procedures may be required (Figure 7.3), possibly with closed-circuit TV monitoring utilizing concrete outbuildings or bunkers.                                                                                                                                                                                                                                                          |
| Consider fire protection, detection and suppression requirements (Chapter 6), and means of escape, alarms, etc.                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Minimize stocks and segregate from other chemicals and work areas. Where appropriate, keep samples dilute or damp and avoid formation of large crystals when practicable. Add stabilizers if possible, e.g. to vinyl monomers. Store in specially-designed, well-labelled containers in 'No Smoking' areas, preferably in several small containers rather than one large container. Where relevant, store in dark and under chilled conditions, except where this causes pure material to separate from stabilizer (e.g. acrylic acid). |
| Do not decant in store.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Consider need for high/low temperature alarms for refrigerated storage; these should be inspected and tested regularly.                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Consider need for mitigatory measures (fire, blast, fragment-resistant barricades/screens), electrical and electrostatic safeguards, personal protection, disposal etc.                                                                                                                                                                                                                                                                                                                                                                 |
| Stores and work areas should be designated 'No Smoking' areas and access controlled. Depending upon scale, explosion-proof electrics and static elimination may be required.                                                                                                                                                                                                                                                                                                                                                            |
| Deal with spillages immediately and make provisions for first aid.                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| All staff should be adequately trained, and written procedures provided.                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

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Table 7.15 gives selected methods for testing explosives.

There is also a range of chemicals, sometimes termed 'blowing agents' (e.g. hydrazides) which decompose at low temperature producing large volumes of gas such as nitrogen and steam. Examples are listed in Table 7.16. Equipment for such products requires special design and a knowledge is required of activators, decomposition rates and temperatures.

## General principles for storage

The general principles for storage of chemicals, which follow from previous summaries, are listed in Table 7.17. Those for compressed gases are given in Chapter 9.

## Hazards arising in chemicals processing

Some factors contributing to chemical process hazards are summarized in Chapter 6: the roles of individual chemicals can be assessed from the preceding part of this chapter.

### *Chemical reaction hazards*

Examples of hazardous reactions are given in Table 7.18. Table 7.19 gives basic precautions in monomer storage; Table 7.20 lists properties of common monomers.

#### *Reaction characteristics*

Reaction in gas, liquid (neat or in solution suspension/emulsion) or solid phase.  
Catalytic or non-catalytic.

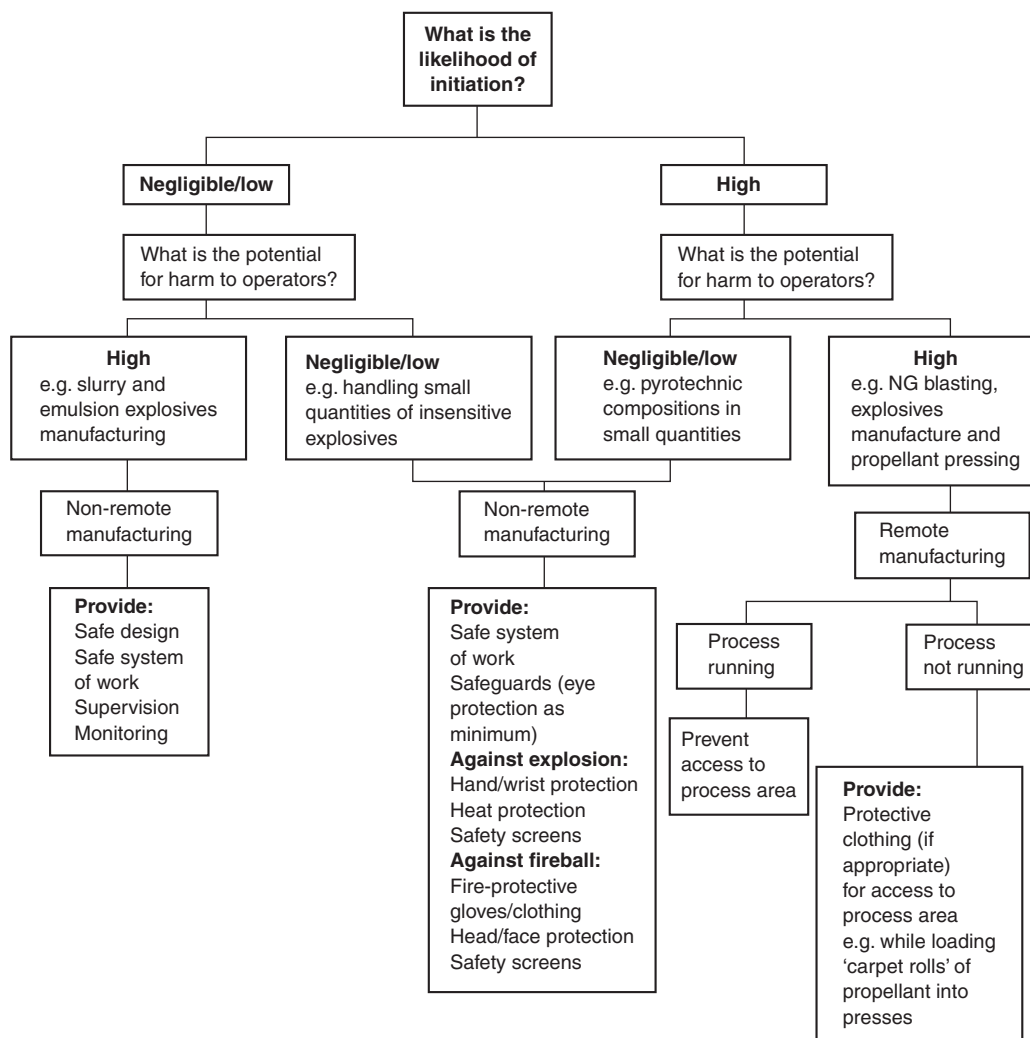


Figure 7.3 Remote versus non-remote manufacturing requirements and fire/explosion safeguards

Exothermic, endothermic, or negligible heat loss/gain.

Reversible or irreversible.

First or second order or complex kinetics.

Reactors may be operated batchwise or continuously, e.g. in tubular, tubes in shell (with or without internal catalyst beds), continuous stirred tank or fluidized bed reactors. Continuous reactors generally offer the advantage of low materials inventory and reduced variation of operating parameters. Recycle of reactants, products or of diluent is often used with continuous reactors, possibly in conjunction with an external heat exchanger.

Adequate heat removal facilities are generally important when controlling the progress of exothermic chemical reactions. Common causes of thermal runaway in reactors or storage tanks are shown in Figure 7.4. A runaway reaction is most likely to occur if all the reactants are initially mixed together with any catalyst in a batch reactor where heat is supplied to start the reaction.

**Table 7.13 Precautions for handling explosives in the laboratory****Storage**

The quantities of potentially explosive materials in store and in use should be strictly limited.

Stores should be specially designed, constructed of non-combustible material, and located away from other hazards (e.g. brick 'coal bunkers' are suitable for small samples, but purpose-built constructions with explosion-proof lights etc. are required for larger quantities). They should be designated 'No Smoking' areas and be well labelled.

Stores should be used exclusively for these materials. Other combustible material such as fabric, paper, organic solvents should not be stored there.

Generally the substances in this class are unstable when heated or exposed to light; they should be stored cool and in the dark. However, for liquids with added stabilizer cooling may cause separation of the material from the stabilizer.

Similarly, precipitation of a potentially explosive compound from a diluent may occur on cooling. In both cases this can represent a hazardous situation.

Stores should be ventilated and sound, e.g. no cracks in floors, no rusty window frames, no water seepages, etc.

Stores should be clean, tidy and locked. Contamination must be avoided and a high standard of housekeeping maintained.

Heat sources should not be permitted nearby.

Material should be purchased in several small containers rather than one large container and always stored in original containers. Integrity of the labels should be checked.

**Use**

Use must be restricted to experienced workers, aware of the hazards and the necessary precautions.

Records of usage should be kept and stock rotated. Old material should be disposed of.

Work should be on a scale of <0.5 g for novel but potentially explosive material until the hazards have been fully evaluated and <5 g for established, commercially available, substances such as peroxide free-radical initiators.

For the above scales, eye protection should be worn and work should be undertaken in a standard fume-cupboard behind a well-anchored polycarbonate screen. It is advisable to wear a protective apron and hand protection; whether leather gauntlets or tongs should be used will be dictated by circumstances. Such measures are recommended but it should be ensured that they do not precipitate a hazard as a result of loss of tactile sensitivity (e.g. dropping a flask, overtightening clamps, exerting excessive pressure when assembling apparatus). The material of gloves needs consideration. (PVC but *not* rubber is suitable for tert-butyl peroxide.)

For large-scale work, armour-plated fume cupboards are likely to be required.

Skin contact, inhalation and ingestion must be avoided. Splashes in eyes or on skin should be washed away immediately with copious quantities of water. Medical attention should be sought. If material is swallowed, medical aid is required immediately.

Glass apparatus should be pickled (e.g. in nitric acid) and thoroughly rinsed after use.

Sources of ignition such as hot surfaces, naked flames etc. must be avoided and smoking prohibited where explosives are used. Accidental application of mechanical energy should be avoided (e.g. material should not be trapped in ground-glass joints): seized stoppers, taps etc. must not be freed by the application of force. To minimize risk of static electricity, laboratory coats of natural fibre rather than synthetic fabrics are preferred. It is important to neutralize any spillage on the coat immediately, since delay could result in the impregnated garment becoming a fire hazard.

To prevent glass fragments from flying in the event of an explosion, use should be made of metal gauzes to screen reaction flasks etc., or cages, e.g. for desiccators. Vessels of awkward size/shape may be covered with cling film.

Whenever possible a stabilizer or diluent should be used and separation of the pure material should be avoided.

Any waste material (and contaminated cloths, tissues, clothing etc.) must be rendered safe by chemical means or by controlled incineration of dilute solution where practical prior to disposal.

In the event of fire, the area should be evacuated, the alarm raised and the fire brigade summoned. Only if it is clearly safe to do so should the fire be tackled with an *appropriate* extinguisher.

**Chemical engineering operations**

Many chemical engineering unit operations may be linked together in chemical processing. The commonest are:

*Fluid mechanics*

Pumping of liquids. Compression of gases

Mixing (solids, liquids, gases; possibly multiphase)

Atomization, dispersion

**Table 7.14 Suggested methods of disposal for commonly encountered explosives**

|                                | <i>Burn</i> | <i>Detone</i> | <i>Dissolve</i> | <i>Chemical</i> | <i>Drowning</i> |
|--------------------------------|-------------|---------------|-----------------|-----------------|-----------------|
| NG-based blasting explosive    | yes         | yes           | no              | no              | yes             |
| ANFO                           | yes         | yes           | yes             | no              | yes             |
| Pyrotechnic compositions       | yes         | no            | yes             | no              | yes             |
| Black powder                   | yes         | no            | yes             | no              | yes             |
| Detonators                     | yes         | yes           | no              | no              | no              |
| Detonating cord                | yes         | yes           | no              | no              | no              |
| Nitroglycerine                 | yes         | no            | no              | yes             | no              |
| Slurry explosive               | yes         | yes           | yes             | no              | yes             |
| Contaminated paper waste       | yes         | no            | no              | no              | no              |
| Fireworks (finished)           | yes         | no            | no              | no              | no              |
| Initiator explosives           | no          | yes           | no              | yes             | no              |
| Propellants                    | yes         | no            | no              | no              | no              |
| Non-NG-based                   |             |               |                 |                 |                 |
| blasting explosives            | yes         | yes           | no              | no              | yes             |
| Shotgun cartridges             | yes         | no            | no              | no              | no              |
| Sporting/small arms ammunition | yes         | no            | no              | no              | no              |

**Table 7.15 Methods for testing explosives**

|                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Flame test</b>                                                                                               | A few crystals (or drop of solution) are heated in the non-luminous flame of a Bunsen burner. Melting with quiet burning is at one end of the spectrum; cracking, flashing-off or flaring are considered hazardous.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Impact</b>                                                                                                   | Impact sensitivity can be gauged by striking a few crystals of the compound on a metal last with the ball of a ball-pein hammer. Ignition, smoking, cracking or other sign of decomposition are considered hazardous.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Differential scanning calorimetry</b><br><b>Differential thermal analysis</b><br><b>Hot stage microscope</b> | If the decomposition reaction follows the general rate law, the activation energy, heat of decomposition, rate constant and half-life for any given temperature can be obtained on a few milligrams using the ASTM method. Hazard indicators include heats of decomposition in excess of 0.3 kcal/g, short half-lives, low activation energies and low exotherm onset temperatures, especially if heat of decomposition is considerable.<br>The DTA or hot-stage microscope can be used under ignition conditions to obtain an ignition temperature. The nature of the decomposition can also be observed at a range of temperatures. Observations such as decomposition with evolution of gases prior to ignition are regarded as potentially hazardous. |
| <b>Bomb calorimetry</b>                                                                                         | Use of oxygen and an inert gas enables the heat of combustion and the heat of decomposition to be evaluated respectively.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Deflagration</b>                                                                                             | A melting point test has been described for diazo compounds. The first 1 mm of a melting-point tube filled with c. 10 mg of test compound is inserted in a melting-point apparatus heated at 270 C. Once decomposition starts, the tube is removed. The decomposition rapidly propagates through the entire mass for unstable diazo compounds; no such propagation is reported for stable versions.                                                                                                                                                                                                                                                                                                                                                       |

### *Heat transfer*

Convective heat exchange, natural or forced

Radiant heat transfer, e.g. furnaces

Evaporation, e.g. in evaporators

Condensation, e.g. in shell and tube heat exchangers

Heat transfer to boiling liquids, e.g. in vaporizers, boilers, re-boilers

**Table 7.16 Substances with a high rate of decomposition**

These substances decompose rapidly to produce large volumes of gas. They are substances not classified as deflagrating or detonating explosives but exhibit violent decomposition when subject to heat.

| <i>Material</i>                                    | <i>Trauzel lead block value (cm<sup>3</sup>/g)</i> | <i>Combustion properties</i>                              |
|----------------------------------------------------|----------------------------------------------------|-----------------------------------------------------------|
| 1:8, Bis (dinitrophenoxy)4,5-dinitro anthraquinone | 18.5                                               | Combustion propagates fully and fast with flame           |
| 100% Dinitrosopentamethylene tetramine             | 18.5                                               |                                                           |
| 2,4-Dinitroaniline                                 | 17.5                                               |                                                           |
| 2-Amino-3,5-dinitrothiophene                       | 13–17.5                                            |                                                           |
| 1:5 Bis (dinitrophenoxy) 4:8-dinitro anthraquinone | 10.5                                               |                                                           |
| 2-formylamino-3,5-dinitrothiophene                 | 8                                                  |                                                           |
| 2-acetyl-amino-3,5-dinitrothiophene                | 7                                                  |                                                           |
| 2-anisidine nitrate                                | 6                                                  |                                                           |
| 80% DNPT                                           | 2.5                                                | Combustion propagates fully and fast by smouldering       |
| 6-nitro-1-diazo-2-naphthol-sulphonic acid          | 5                                                  |                                                           |
| Ammonium nitrate                                   | 23                                                 | Local decomposition – no propagation of the decomposition |
| 2-bromo-4,6-dinitroaniline                         | 17.5                                               |                                                           |
| 6-bromo-2,4-dinitroaniline                         | 17                                                 |                                                           |
| 2-chloro-4,6-dinitroaniline                        | 16.5                                               |                                                           |

This substance exhibits a high rate of decomposition without combustion when exposed to heat and certain initiators.

| <i>Material</i>                          | <i>Decomposition temperature</i> | <i>Property</i>           |
|------------------------------------------|----------------------------------|---------------------------|
| P,P'-oxybis (benzenesulphonyl hydrazide) | 150 C                            | Decomposes and propagates |

*Mass transfer operations (in which a material is transferred across a phase boundary or interface)*

Distillation, either batchwise or continuous

Liquid–liquid extraction (solvent extraction)

Solid–liquid extraction (leaching)

Gas absorption, scrubbing; desorption, stripping

Humidification and water cooling

Dehumidification and air conditioning

Drying of solids, solutions/slurries

Adsorption (in which a gas or liquid is taken up on a solid, e.g. activated charcoal, molecular sieves)

Crystallization

Less common means of separation, e.g. dialysis, ion-exchange, osmosis, chromatography, electrophoresis.

*Non-mass transfer operations*

Filtration of suspensions, e.g. in filter presses, rotary vacuum filters

Sedimentation, gravity settling

Centrifugation, for immiscible liquid or solid separation and recovery

Classification by sieving, screening

Size reduction, e.g. milling, crushing, grinding

**Table 7.17 General principles for chemical storage**


---

|                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Store minimum quantities                                                                                                                                                                                                                                        |
| Control stock, i.e. first-in/first-out, move redundant stock                                                                                                                                                                                                    |
| Segregate chemicals, e.g. from water, air, incompatible chemicals, sources of heat, ignition sources                                                                                                                                                            |
| Segregate 'empties', e.g. cylinders, sacks, drums, bottles                                                                                                                                                                                                      |
| Monitor stock, e.g. temperature, pressure, reaction, inhibitor content, degradation of substance, deterioration of packaging or containers/corrosion, leakages, condition of label, expiry date, undesirable by-products (e.g. peroxides in ethers)             |
| Spillage control; bund, spray, blanket, containment. Drain to collection pit                                                                                                                                                                                    |
| Decontamination and first-aid provisions, e.g. neutralize/destroy, fire-fighting                                                                                                                                                                                |
| Contain/vent pressure generated to a safe area                                                                                                                                                                                                                  |
| Store in 'safest' form, e.g. as pre-polymers, as chemical for generation of requirements (e.g. hypochlorites for chlorine) in dilute form                                                                                                                       |
| Handle solids as prills or pellets rather than powders to minimize the possibility of dust formation                                                                                                                                                            |
| Split-up stocks into manageable lots, e.g. with reference to fire loading/spillage control. Limit stack heights; generally chemicals should be stored off the ground (e.g. to facilitate cleaning, to keep above any ingress of water in the event of flooding) |
| Select correct materials of construction; allow for reduction in resistance due to dilution/concentration, presence of impurities, catalytic effects                                                                                                            |
| Transport infrequently to minimize stocks for both safety and to reduce costs and environmental hazards arising from the need to dispose of surplus or expired material                                                                                         |
| Ensure appropriate levels of security, hazard warning notices, fences, patrols. Control access including vehicles                                                                                                                                               |
| Segregate/seal drains                                                                                                                                                                                                                                           |
| Appropriate gas/vapour/fume/pressure venting, e.g. flame arrestors, scrubbers, absorbers, stacks                                                                                                                                                                |
| Ensure adequate natural or forced general ventilation of the storage area                                                                                                                                                                                       |
| Provide adequate, safe lighting                                                                                                                                                                                                                                 |
| Label (name and number); identify loading/unloading/transfer couplings                                                                                                                                                                                          |
| Facilitate sampling (for quality assurance and stock monitoring)                                                                                                                                                                                                |
| Provide appropriate fire protection (sprinkler, dry powder, gas)                                                                                                                                                                                                |
| Consider spacings from buildings, road, fence                                                                                                                                                                                                                   |
| Ensure adequate access for both normal and emergency purposes with alternative routes                                                                                                                                                                           |
| Protect from vehicle impact, e.g. by bollards                                                                                                                                                                                                                   |
| Assign responsibility for administration, maintenance, cleaning and general housekeeping                                                                                                                                                                        |

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Gas cleaning by filtration, demisting, electrostatic precipitation, wet collection of particulates, cyclonic separation.

Dependent upon the chemicals in-process, each of these may introduce a range of hazards, e.g. chemical, flammable or mechanical. These must be checked in every case. Safety features which may be required are summarized in Table 7.21.

Common reaction rate v. temperature characteristics for reactions are illustrated in Figure 7.5. To avoid runaway conditions (Fig. 7.5a) or an explosion (Figure 7.5c), control may involve:

- Use of dilute solutions, emulsions, or suspensions.
- Feeding one reactant in at a controlled rate depending upon reactant's temperature.
- Refluxing of solvent from a condenser.
- Imposing a limit on reactor size, to ensure adequate heat transfer area per unit volume.
- Careful selection of reactant and coolant temperature.
- Provision of efficient agitation.

Mitigation of a runaway reaction may involve:

- Emergency cooling.
- Dumping of reactants into an empty vessel or one containing a compatible quenching liquid.

**Table 7.18 Characteristics of some different types of reaction**

|                                |                                                                                                                                                                                                                                                                                                                                                                                                                        |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Oxidation</b>               | Feedstocks generally hydrocarbons<br>Hazard of fire/explosion arises from contact of flammable material with oxygen<br>Reactions highly exothermic: equilibrium favours complete reaction                                                                                                                                                                                                                              |
| <b>Polymerization</b>          | Exothermic reaction which, unless carefully controlled, can run-away and create a thermal explosion or vessel overpressurization<br>Refer to Table 7.20 for common monomers<br>Certain processes require polymerization of feedstock at high pressure, with associated hazards<br>Many vinyl monomers (e.g. vinyl chloride, acrylonitrile) pose a chronic toxicity hazard<br>Refer to Table 7.19 for basic precautions |
| <b>Halogenation</b>            | The commercially important halogens are chlorine, bromine, fluorine, iodine. Refer to Table 5.19 for properties<br>All are highly toxic<br>Reactions are highly exothermic and chain reactions can occur, which may result in detonation                                                                                                                                                                               |
| <b>Hydroprocesses</b>          | Hydrogen is chemically stable and relatively unreactive at ordinary temperatures; most processes utilizing it require a catalyst. Above 500 C it reacts readily with oxygen and confined flammable mixtures explode violently if ignited<br>Main hazards: fire, explosion, metallurgical problems arising from hydrogen attack                                                                                         |
| <b>Nitration</b>               | Hazards arise from the strong oxidizing nature of the nitrating agents used (e.g. mixture of nitric and sulphuric acids) and from the explosive characteristics of some end products<br>Reactions and side reactions involving oxidation are highly exothermic and may occur rapidly<br>Sensitive temperature control is essential to avoid run-away                                                                   |
| <b>Alkylation</b>              | Hazards arise from the alkylating agents, e.g. dimethyl sulphate (suspected human carcinogen), hydrogen fluoride (highly toxic irritant gas)<br>Thermal alkylation processes require higher temperatures and pressures, with associated problems                                                                                                                                                                       |
| <b>High pressure reactions</b> | High inventories of stored pressure (e.g. in pressurized reactors or associated plant) can result in catastrophic failure of the pressure shell                                                                                                                                                                                                                                                                        |

**Table 7.19 Basic precautions in monomer storage****Indoors**

Cool, well-ventilated area  
Non-combustible construction  
Segregated from other flammables/reactants

**Outdoors**

Well-spaced tanks, possibly with water cooling, refrigeration, buried  
Some monomers (e.g. acrylic acid) may require provisions to avoid freezing  
Provision for inhibitor/stabilizer addition  
Provision for atmosphere inerting may be required

Venting to a knock-out vessel, to remove non-gaseous substances. (This may be followed by a scrubbing unit for gases or a flare-stack.)

The kinetics and thermodynamics of the reaction, and of possible side reactions, need to be understood. The explosive potential of chemicals liable to exothermic reaction should be carefully appraised.

A thorough assessment should be made before undertaking:



Table 7.20 Properties of common monomers

|                                                                                       | Flash<br>point<br>( C ) | Ignition<br>temp.<br>( C ) | Flammable<br>limits<br>(% by vol.<br>in air) | Specific<br>gravity<br>(Water<br>= 1.0) | Vapour<br>density<br>(Air = 1.0) | Boiling<br>point<br>( C ) | Properties                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------------|-------------------------|----------------------------|----------------------------------------------|-----------------------------------------|----------------------------------|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Acetaldehyde<br>(Acetic aldehyde,<br>ethanal)<br>$\text{CH}_3\text{CHO}$              | -38                     | 185                        | 4.0–55.0                                     | 0.8                                     | 1.5                              | 21                        | Colourless fuming liquid<br>Pungent odour<br>Irritant<br>Water soluble<br>Can polymerize<br>exothermically, form<br>explosive peroxides, or<br>react violently with other<br>chemicals                                                |
| Acrolein<br>(Allyl aldehyde,<br>propenal)<br>$\text{CH}_2\text{:CHCHO}$               | -26                     | 278                        | 2.8–31.0                                     | 0.8                                     | 1.9                              | 53                        | Colourless/yellow liquid<br>Pungent unpleasant odour<br>Water soluble<br>Irritant<br>Can polymerize<br>exothermically with<br>strong alkalis, heat or light<br>Can form peroxides                                                     |
| Acrylic acid<br>(Propenoic acid,<br>propene acid)<br>$\text{CH}_2\text{:CHCOOH}$      | 54                      | —                          | —                                            | 1.1                                     | 2.5                              | 140                       | Colourless, water soluble<br>liquid<br>Freezing point 14 C<br>Polymerizes readily with<br>oxygen<br>Must be inhibited                                                                                                                 |
| Acrylonitrile<br>(Vinyl cyanide,<br>propenenitrile)<br>$\text{CH}_2\text{:CHCN}$      | 0                       | 481                        | 3.0–17.0                                     | 0.8                                     | 1.8                              | 77                        | Colourless, partially water<br>soluble liquid<br>Experimental carcinogen<br>Polymerizes violently with<br>organic peroxides or<br>concentrated caustic<br>alkalis<br>Highly toxic<br>Usually inhibited                                |
| 1,3-Butadiene<br>(Butadiene,<br>vinylethylene)<br>$\text{CH}_2\text{:CHCH:CH}_2$      | -76                     | 450                        | 2.0–11.5                                     | 0.6                                     | 1.9                              | -4                        | Colourless, odourless<br>liquefiable gas<br>Polymerizes readily,<br>particularly if $\text{O}_2$ or<br>traces of catalyst present<br>Can form explosive peroxides<br>Normally contains inhibitor<br>(liquid phase) and<br>antioxidant |
| Epichlorhydrin<br>(Chloropropylene<br>oxide)<br>$\text{CH}_2\text{:OCHCH}_2\text{Cl}$ | 32                      | —                          | —                                            | 1.2                                     | 3.3                              | 115                       | Colourless, partly water<br>soluble liquid<br>Highly toxic<br>Polymerizes exothermically<br>with acids, bases, certain<br>salts and catalysts<br>Can react with water                                                                 |
| Ethyl acrylate<br>$\text{CH}_2\text{:CHCOOC}_2\text{H}_5$                             | 15                      | —                          | 1.8—                                         | 1.2                                     | —                                | 100                       | Colourless liquid<br>Acrid odour<br>Polymerizes readily,<br>accelerated by heat, light,<br>organic peroxides<br>Irritant                                                                                                              |

Table 7.20 Cont'd

|                                                                                                                                         | Flash<br>point<br>(°C) | Ignition<br>temp.<br>(°C) | Flammable<br>limits<br>(% by vol.<br>in air) | Specific<br>gravity<br>(Water<br>= 1.0) | Vapour<br>density<br>(Air = 1.0) | Boiling<br>point<br>(°C) | Properties                                                                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------|---------------------------|----------------------------------------------|-----------------------------------------|----------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ethylene oxide<br>CH <sub>2</sub> :CH <sub>2</sub><br> | <-18                   | 429                       | 3.0-100                                      | 0.9                                     | 1.5                              | 11                       | Colourless gas at room temperature<br>Irritant to eyes and respiratory tract, and an experimental carcinogen<br>Polymerizes uncontrollably with immense explosive force on contact with certain chemicals (e.g. ammonia) |
| Formaldehyde<br>(Oxymethylene)<br>HCHO                                                                                                  | gas                    | 430                       | 7.0-73.0                                     | —                                       | 1.1                              | -21                      | Colourless<br>Water soluble gas producing formalin solutions<br>Suffocating odour<br>Polymerizes readily<br>Highly toxic<br>Respiratory sensitizer                                                                       |
| Methacrylic acid<br>CH <sub>2</sub> :C(CH <sub>3</sub> )COOH                                                                            | 77                     | —                         | —                                            | —                                       | —                                | 158                      | Colourless, water soluble liquid<br>Polymerizes readily unless inhibited or stored <15°C                                                                                                                                 |
| Methyl acrylate<br>CH <sub>2</sub> :CHCOOCH <sub>3</sub>                                                                                | -3                     | —                         | 2.8-25.0                                     | 1.0                                     | 3.0                              | 80                       | Irritant<br>Colourless liquid<br>Acrid odour<br>Extremely irritating to respiratory system, skin and mucous membranes                                                                                                    |
| Methyl methacrylate<br>CH <sub>2</sub> :C(CH <sub>3</sub> )COOCH <sub>3</sub>                                                           | 29                     | —                         | 2.1-12.5                                     | 0.9                                     | 3.4                              | 101                      | Colourless liquid<br>Acrid odour                                                                                                                                                                                         |
| Styrene<br>(Vinyl benzene)<br>C <sub>6</sub> H <sub>5</sub> CH:CH <sub>2</sub>                                                          | 32                     | 490                       | 1.1-6.1                                      | 0.9                                     | 3.6                              | 145                      | Colourless/oily yellow liquid<br>Penetrating odour<br>Polymerizes slowly in air or light, accelerated by heat or catalysts<br>Ignition/explosion possible<br>Usually inhibited<br>Store <21°C                            |
| Vinyl acetate<br>CH <sub>3</sub> COOCH:CH <sub>2</sub>                                                                                  | -8                     | 427                       | 2.6-13.4                                     | 1.1                                     | 3.0                              | 72                       | Colourless, partially water soluble liquid<br>Faint odour<br>Polymerizes with heat or organic peroxides                                                                                                                  |
| Vinyl chloride<br>(Chloroethene)<br>CH <sub>2</sub> :CHCl                                                                               | -78                    | 472                       | 4.0-22.0                                     | 1.0                                     | 2.1                              | -14                      | Colourless, sweet smelling liquefiable gas<br>Polymerizes with light, heat, air or catalysts<br>Normally inhibited<br>Human carcinogen                                                                                   |
| Vinylidene chloride<br>(Dichloroethylene-1,1)<br>CH <sub>2</sub> :CCl <sub>2</sub>                                                      | -10                    | 458                       | 5.6-11.4                                     | 1.3                                     | 3.3                              | 37                       | Colourless volatile liquid<br>Polymerizes unless inhibited<br>Decomposes at 457°C                                                                                                                                        |

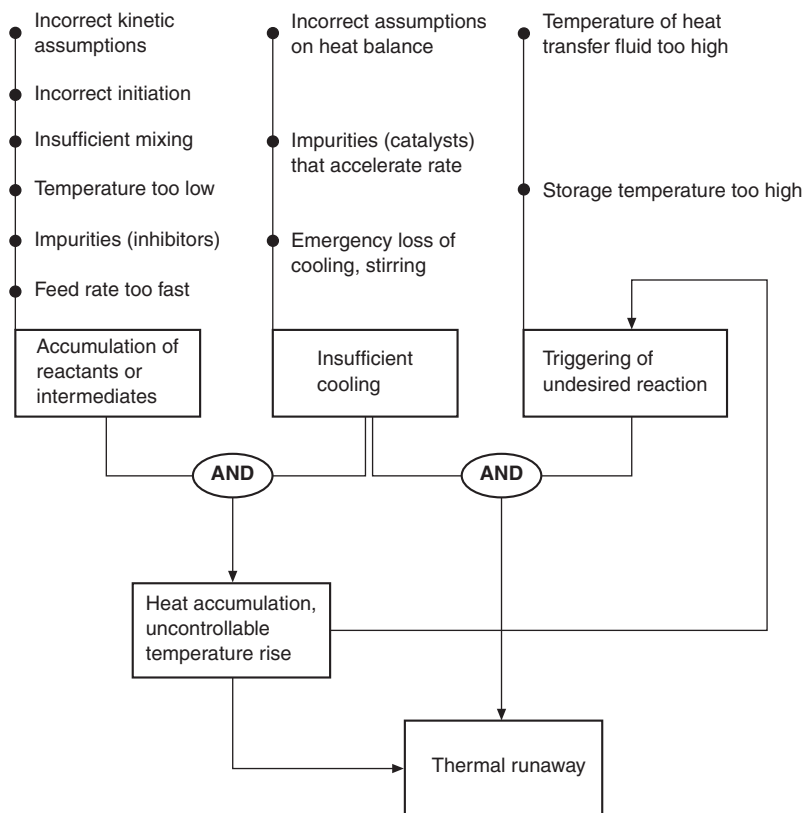


Figure 7.4 Common causes of thermal runaway in reactors or storage tanks

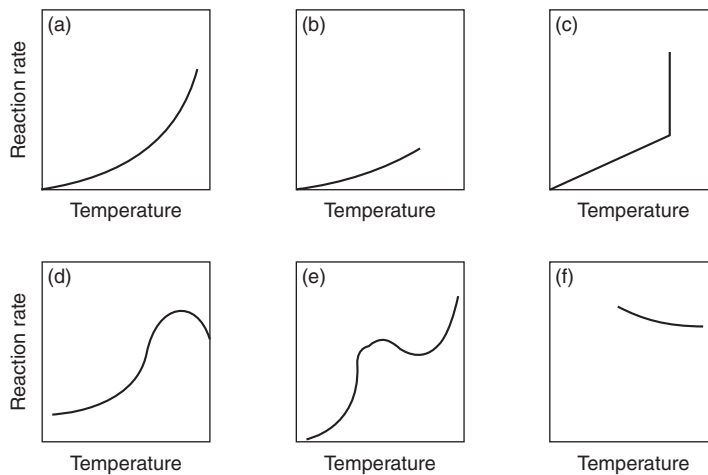


Figure 7.5 Types of reaction rate/temperature curve

- Rapid increase with temperature – normal characteristic
- Slow increase in rate with temperature – characteristic of some heterogeneous reactions
- Very rapid increase at one point – the ignition point in an explosion
- Decrease in rate at higher temperature – characteristic of catalytic reactions
- Decrease in rate at intermediate temperatures, followed by an increase
- Slow decrease in rate with temperature

Table 7.21 Safety features in chemical engineering operations

|                             |                                                                                                                                                                                                                                                                                                                      |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Inventory</b>            | Reduce inventory of chemicals:<br>Continuous operation may be preferable to batch<br>Low residence time contacting equipment may be better than cheaper alternatives etc.                                                                                                                                            |
| <b>Monitoring</b>           | Monitor temperature, pressure flow, composition, freedom from contamination and other appropriate properties of all streams where relevant. Consider automatic control                                                                                                                                               |
| <b>Isolation</b>            | Provide for isolation from upstream and downstream operations. Consider provision of automatic and/or remotely operated isolation. Consider isolation for cleaning needs                                                                                                                                             |
| <b>Contaminants</b>         | Provide measures to remove unacceptable contaminants from feed materials, process streams and services, e.g. entrained liquid, tramp metal, unwanted particulate solids                                                                                                                                              |
| <b>Pressure/temperature</b> | Operate at moderate temperature and pressure where possible. Avoid superheated liquids, which will flash-off, if practicable<br>Allow for effects of over-/under-temperature, over-/under-pressure. Following assessment (e.g. by HAZOP)                                                                             |
| <b>Continuous flow</b>      | With continuous flow operations consider (e.g. using a HAZOP procedure) the effects of:<br>No flow<br>Reduced flow<br>Reverse flow<br>Increased flow<br>Contaminated flow<br>Flow of a substituted material, etc.                                                                                                    |
| <b>Start-up/shutdown</b>    | Provide for safe start-up, including purging if necessary<br>Provide for safe shutdown:<br>Normal<br>By a trip<br>On standby<br>In various emergency situations, etc.                                                                                                                                                |
| <b>Instrumentation</b>      | Provide safety instrumentation in addition to process instrumentation<br>Consider high-high and low-low alarms. Consider automatic activation of emergency responses, e.g. venting, emergency cooling, recycling, discharge of liquid streams, shutdown<br>High/low temperature<br>pressure<br>flow<br>level<br>etc. |
| <b>Protective features</b>  | linked to trips for automatic operation where appropriate<br>Provide protective as well as control features, e.g. pressure and vacuum relief, explosion suppression relief, advance inerting, containment                                                                                                            |
| <b>Waste streams</b>        | Cater for routine and emergency, safe discharge of all waste streams, e.g. atmospheric venting, possibly after treatment, discharge of liquid effluents including out-of-specification streams, discharges of particulate or bulk solids                                                                             |
| <b>Common-mode failure</b>  | Avoid common-mode failure possibilities with services, control systems, safety systems etc.                                                                                                                                                                                                                          |

Scale-up (since it may result in a decrease in heat transfer capacity per unit mass of reactant).  
Modifications in reactor geometry, agitation and control (e.g. instrumentation, cooling, venting).  
Changes in reaction materials, (e.g. source, purity, concentration), diluents, catalysts charging procedures.  
Changes in operating conditions.

The characteristics of some potentially hazardous reactions are summarized in Tables 7.18 and 7.22.

Many processes require equipment designed to rigid specifications together with automatic control and safety devices. Consideration should be given to the control, and limitation of the effects, of equipment malfunction or maloperation including:

Table 7.22 Hazard rating of chemical reactions

| Reaction                                                                               | Degree of hazard | Reaction                                                                                                                                                                                                                              | Degree of hazard |
|----------------------------------------------------------------------------------------|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| <b>Reduction</b>                                                                       |                  | Formaldehyde – hydrochloric acid                                                                                                                                                                                                      | E                |
| Clemmensen                                                                             | D                | Ethylene oxide                                                                                                                                                                                                                        | C                |
| Sodium-amalgam                                                                         | D                | Dialkyl sulphate                                                                                                                                                                                                                      | D                |
| Zinc–acetic acid                                                                       | E                | Diazoalkane                                                                                                                                                                                                                           | A                |
| Zinc–hydrochloric acid                                                                 | E                |                                                                                                                                                                                                                                       |                  |
| Zinc–sodium hydroxide                                                                  | E                | <b>Carbon–nitrogen</b>                                                                                                                                                                                                                |                  |
| Ferrous ammonium sulphate                                                              | E                | Cyanomethylation                                                                                                                                                                                                                      | C                |
| Lead tetraacetate                                                                      | E                | Chloromethylation                                                                                                                                                                                                                     | D                |
| Meerwein–Pondorff                                                                      | D                | Ethylenimine                                                                                                                                                                                                                          | C                |
| Lithium aluminium hydride                                                              | B                | Ethylene oxide                                                                                                                                                                                                                        | C                |
| Dialkyl aluminium hydride                                                              | B                | Quaternization                                                                                                                                                                                                                        | D                |
| Rosenmund                                                                              | A                |                                                                                                                                                                                                                                       |                  |
| Catalytic high pressure                                                                | A                | <b>Condensation</b>                                                                                                                                                                                                                   |                  |
| Catalytic low pressure                                                                 | B                | Erlenmeyer                                                                                                                                                                                                                            | D                |
| <b>Oxidation</b>                                                                       |                  | Perkin                                                                                                                                                                                                                                | D                |
| Hydrogen peroxide – dilute aqueous                                                     | E                | Acetoacetic ester                                                                                                                                                                                                                     | D                |
| Air or I <sub>2</sub> (mercaptan to disulphide)                                        | D                | Aldol                                                                                                                                                                                                                                 | D                |
| Oppenauer                                                                              | D                | Claisen                                                                                                                                                                                                                               | D                |
| Selenium dioxide                                                                       | D                | Knoevenagel                                                                                                                                                                                                                           | D                |
| Aqueous solution nitric acid, permanganate, manganic dioxide, chromic acid, dichromate | E                | Condensations using catalysts such as phosphoric acid; AlCl <sub>3</sub> ; KHSO <sub>4</sub> ; SnCl <sub>4</sub> ; H <sub>2</sub> SO <sub>4</sub> ; ZnCl <sub>2</sub> NaHSO <sub>2</sub> ; POCl <sub>2</sub> ; HCl; FeCl <sub>2</sub> | E                |
| Electrolytic                                                                           | B                | Acyloin                                                                                                                                                                                                                               | C                |
| Chromyl chloride                                                                       | C                | Diketones with hydrogen sulphide                                                                                                                                                                                                      | C                |
| Ozonolysis                                                                             | A                | Diketones with diamines→quinazolines                                                                                                                                                                                                  | D                |
| Nitrous acids                                                                          | A                | Diketones with NH <sub>2</sub> OH→isoxazolines                                                                                                                                                                                        | D                |
| Peracids – low molecular weight or two or more positive groups                         | A                | Diketones with NH <sub>2</sub> NH <sub>2</sub> →pyrazoles                                                                                                                                                                             | C                |
| Peracids – high molecular weight                                                       | B                | Diketones with semicarbazide→pyrazoles                                                                                                                                                                                                | D                |
| <i>t</i> -Butyl hypochlorite                                                           | C                | Diketones with ammonia→pyrazoles                                                                                                                                                                                                      | D                |
| Chlorine                                                                               | C                | Carbon disulphide with aminoacetamide→thiazolone                                                                                                                                                                                      | A                |
| <b>Alkylation</b>                                                                      |                  | Nitriles and ethylene diamines→imidazolines                                                                                                                                                                                           | D                |
| <b>Carbon–carbon</b>                                                                   |                  | <b>Amination</b>                                                                                                                                                                                                                      |                  |
| Alkali metal                                                                           | C                | Liquid ammonia                                                                                                                                                                                                                        | B                |
| Alkali metal alcoholate                                                                | D                | Aqueous ammonia                                                                                                                                                                                                                       | E                |
| Alkali metal amides and hydrides                                                       | C                | Alkali amides                                                                                                                                                                                                                         | C                |
| Reformatsky                                                                            | E                |                                                                                                                                                                                                                                       |                  |
| Michael                                                                                | E                | <b>Esterification</b>                                                                                                                                                                                                                 |                  |
| Grignard                                                                               | B                | Inorganic                                                                                                                                                                                                                             | E                |
| Organometallics, such as dialkyl zinc or cadmium–alkyl or aryl lithium                 | B                | Alkoxy magnesium halides                                                                                                                                                                                                              | B                |
| Alkali acetylides                                                                      | A                | Organic:                                                                                                                                                                                                                              |                  |
| Diels–Alder                                                                            | D                | Alcohol and acids or acid chloride or acid anhydride                                                                                                                                                                                  | D                |
| Arndt–Eistert                                                                          | A                | Alkyl halide and silver salts of acids                                                                                                                                                                                                | E                |
| Diazoalkane and aldehyde                                                               | A                | Alkyl sulphate and alkali metal salt of acid                                                                                                                                                                                          | D                |
| Aldehydes or ketones and hydrogen cyanide                                              | C                | Alkyl chlorosulphates and                                                                                                                                                                                                             |                  |
| <b>Carbon–oxygen</b>                                                                   |                  |                                                                                                                                                                                                                                       |                  |
| Williamson                                                                             | D                |                                                                                                                                                                                                                                       |                  |

Table 7.22 Hazard rating of chemical reactions

| Reaction                                                  | Degree of hazard | Reaction                                                                                   | Degree of hazard |
|-----------------------------------------------------------|------------------|--------------------------------------------------------------------------------------------|------------------|
| alkali salts of carboxylic acid                           | D                | <b>Pyrolysis</b>                                                                           |                  |
| Ester-exchange                                            | D                | Atmospheric pressure                                                                       | D                |
| Carboxylic acid and diazomethane                          | A                | Pressure                                                                                   | B                |
| Acetylene and carboxylic acid-vinyl ester                 | A                | <b>Schmidt</b>                                                                             | B                |
| <b>Hydrolysis, aqueous nitriles, esters</b>               | E                | <b>Mannich</b>                                                                             | D                |
| <b>Simple metathetical replacement</b>                    | D                | <b>Halogenation</b>                                                                        |                  |
| <b>Preparation and reaction of peroxides and peracids</b> |                  | SO <sub>2</sub> X <sub>2</sub> , SOX <sub>2</sub> , SX, POX <sub>2</sub> , PX <sub>5</sub> | D                |
| Concentrated                                              | A                | HX                                                                                         | D                |
| Dilute                                                    | D                | Cl <sub>2</sub> , Br <sub>2</sub>                                                          | C                |
|                                                           |                  | <b>Nitration</b>                                                                           |                  |
|                                                           |                  | Dilute                                                                                     | D                |
|                                                           |                  | Concentrated                                                                               | B                |

*Hazardous*

- A Highly flammable  
Develops high pressure instantly  
Highly toxic

*Special*

- B Flammable, perhaps explosive, mixtures form  
C Flammable, or generates toxic substances

*Conventional*

- D Slightly flammable  
Generates or uses mildly toxic substances  
E Non-flammable  
Does not use or generate toxic substances

**Named reactions**

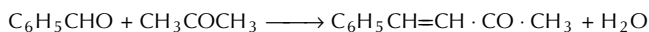
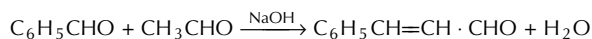
**Aldol reaction** is the condensation of an aldehyde to produce longer-chain hydroxy aldehydes



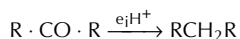
**Arndt-Eistert** reaction is used to convert an acid compound into the next higher homologue by reaction with diazomethane



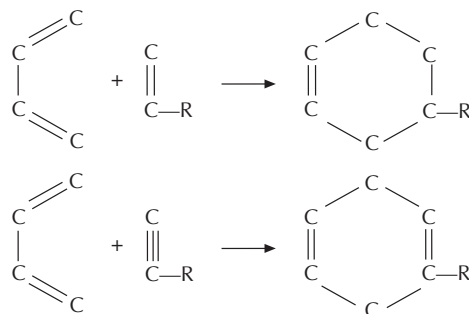
**Claisen reaction** is the condensation of benzaldehyde with aliphatic aldehydes and ketones containing  $\alpha$ -hydrogen



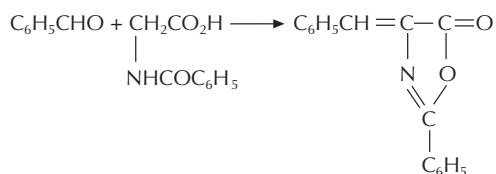
**Clemmensen reaction** is the reduction of carbonyl compounds with amalgamated zinc and concentrated hydrochloric acid



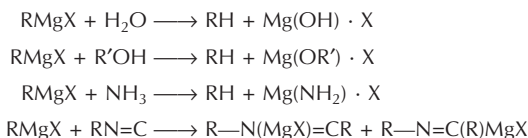
**Diels-Alder** is the preparation of cyclic olefins from dienes and a dienophile



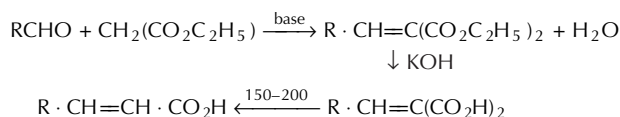
**Erlenmeyer reaction** is the condensation of aromatic aldehydes with hippuric acid to form azlactones (important intermediates in the preparation of amino- and keto-acids)



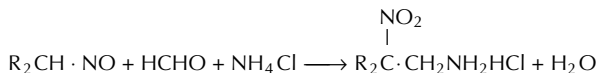
**Grignard reaction** is the use of alkyl magnesium halides to form a host of products by reaction with a variety of chemicals



**Knoevenagel reaction** is the synthesis of  $\alpha$ ,  $\beta$ -unsaturated acids by reaction of aldehydes and compounds with active methylene groups in the presence of an organic base



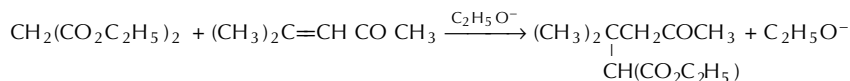
**Mannich reaction** is the condensation between formaldehyde, ammonia, or a primary or secondary amine (preferably as the hydrochloride), and a compound containing at least one active hydrogen atom



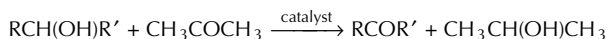
**Meerwein-Ponndorf reduction** is the synthesis of alcohols by heating carbonyl compounds with aluminium isopropoxide in isopropanol and distilling off acetone by-product



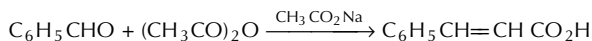
**Michael condensation** is the addition of a compound with an active methylene group to an  $\alpha$ ,  $\beta$ -unsaturated keto-compound



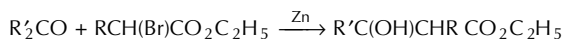
**Oppenauer reaction** is oxidation of secondary alcohols to ketones using aluminium t-butoxide



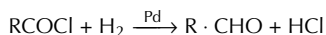
**Perkin condensation** is the reaction between aromatic aldehydes and aliphatic acid anhydrides (in the presence of the sodium salt) to form  $\beta$ -arylacrylic acid



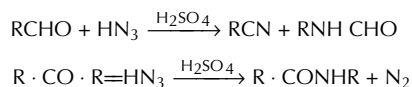
**Reformatsky reaction** is the formation of  $\beta$ -hydroxyesters by reaction of  $\alpha$ -bromoacid ester and a carbonyl compound, usually in the presence of zinc



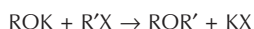
**Rosenmund reaction** is the action between acid chloride and hydrogen in the presence of palladium catalyst to produce aldehydes



**Schmidt reaction** is the reaction between carbonyl compounds and hydrazoic acid in the presence of e.g. concentrated sulphuric acid



**Williamson reaction** is the synthesis of ethers by action of heat on a mixture of alkyl halide and sodium or potassium alkoxide



Stirrer failure, mechanical or electrical.

Attainment of abnormal reaction conditions, e.g. overpressure, over-temperature, segregation of reactants, excessive reaction rate, initiation of side reactions.

Power failure, affecting agitator, pumps, instruments.

Error in valve, switch or associated equipment operation.

Failure to actuate agitation at the proper time.

Instrument failure, pressure, flow, temperature, level or a reaction parameter, e.g. concentration.

Failure of instrument air or electricity.

Loss of inert gas blanket.

Failure of relief devices, e.g. pressure relief valves or rupture discs.

Failure of coolant, refrigerant, or other utilities.

Failure of high or low pressure alarms or cut-outs.

Addition of wrong material or wrong quantities.

Addition of materials in incorrect sequence.

Failure to add material, e.g. short-stop or inhibitor, at correct stage.

Spillage of material.

Improper venting to atmosphere, i.e. other than via vents with flame arresters or scrubbers, or via a knockout drum, or to the correct flare systems.

Restricted or blocked vent.

Restricted material flows in or out.

Leakage of *materials out*, e.g. due to a gasket failure, or *air in*.



# Cryogenics

Cryogenics, or low-temperature technology, is the science of producing and maintaining very low temperatures usually below 120 K, as distinct from traditional refrigeration which covers the temperature range 120 to 273.1 K. At or below 120 K, the permanent gases including argon, helium, hydrogen, methane, oxygen and nitrogen can be liquefied at ambient pressure as exemplified by Table 8.1. Any object may be cooled to low temperatures by placing it in thermal contact with a suitable liquefied gas held at constant pressure. Applications can be found in food processing, rocket propulsion, microbiology, electronics, medicine, metal working and general laboratory operations. Cryogenic technology has also been used to produce low-cost, high-purity gases through fractional condensation and distillation. Cryogenics are used to enhance the speed of computers and in magnetic resonance imaging to cool high conductivity magnets for non-intrusive body diagnostics. Low-temperature infrared detectors are used in astronomical telescopes.

**Table 8.1 Properties of common cryogenics**

| <i>Gas</i>             | <i>Boiling point<br/>( °C )</i> | <i>Volume of gas produced on evaporation<br/>of 1 litre of liquid (litres)</i> |
|------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Helium                 | – 269                           | 757                                                                            |
| Hydrogen               | – 253                           | 851                                                                            |
| Neon                   | – 246                           | 1438                                                                           |
| Nitrogen               | – 196                           | 696                                                                            |
| Fluorine               | – 187                           | 888                                                                            |
| Argon                  | – 186                           | 847                                                                            |
| Oxygen                 | – 183                           | 860                                                                            |
| Methane                | – 161                           | 578                                                                            |
| Krypton                | – 151                           | 700                                                                            |
| Xenon                  | – 109                           | 573                                                                            |
| Chlorotrifluoromethane | – 81                            | –                                                                              |
| Carbon dioxide         | – 78.5                          | 553                                                                            |

Every gas has a critical temperature above which it cannot be liquefied by application of pressure alone (Chapter 4). As a result, gases used, e.g., as an inert medium to reduce oxygen content of atmospheres containing flammable gas or vapour (Chapter 6) are often shipped and stored as cryogenic liquid for convenience and economy.

In the laboratory, a range of ‘slush baths’ may be used for speciality work. These are prepared by cooling organic liquids to their melting points by the addition of liquid nitrogen. Common examples are given in Table 8.2. Unless strict handling precautions are instituted, it is advisable to replace the more toxic and flammable solvents by safer alternatives.

**Table 8.2 Working temperatures of cryogenic slush baths**

| <i>Bath liquid</i>                              | <i>Temperature<br/>( °C )</i> |
|-------------------------------------------------|-------------------------------|
| Carbon tetrachloride                            | – 23                          |
| Chlorobenzene                                   | – 45                          |
| Solid carbon dioxide                            | – 63                          |
| in acetone or methylated spirits <sup>(1)</sup> | – 78                          |
| Toluene                                         | – 95                          |
| Carbon disulphide                               | – 112                         |
| Diethyl ether                                   | – 120                         |
| Petroleum ether                                 | – 140                         |

<sup>(1)</sup>Liquid nitrogen is omitted from this mixture and the solvent is used to improve the heat transfer characteristics of cardice.

Typical insulating materials include purged rockwool or perlite, rigid foam such as foam-glass or urethane, or vacuum. However, because perfect insulation is not possible heat leakage occurs and the liquefied gas eventually boils away. Uncontrolled release of a cryogen from storage or during handling must be carefully considered at the design stage. The main hazards with cryogens stem from:

The low temperature which, if the materials come into contact with the body, can cause severe tissue burns. Flesh may stick fast to cold uninsulated pipes or vessels and tear on attempting to withdraw it. The low temperatures may also cause failure of service materials due to embrittlement; metals can become sensitive to fracture by shock.

Asphyxiation (except with oxygen) if the cryogen evaporates in a confined space.

The very large vapour-to-liquid ratios (Table 8.1) so that a large cloud, with fog, results from loss of liquid.

Catastrophic failure of containers as cryogen evaporates to cause pressure build-up within the vessel beyond its safe working pressure (e.g. pressures  $\leq 280\,000$  kPa or 40 600 psi can develop when liquid nitrogen is heated to ambient temperature in a confined space).

Flammability (e.g. hydrogen, acetylene, methane), toxicity (e.g. carbon dioxide, fluorine), or chemical reactivity (fluorine, oxygen).

Trace impurities in the feed streams can lead to combination of an oxidant with a flammable material (e.g. acetylene in liquid oxygen, solid oxygen in liquid hydrogen) and precautions must be taken to eliminate them.

Several materials react with pure oxygen so care in selection of materials in contact with oxygen including cleaning agents is crucial.

Key precautions are given in Table 8.3.

The cryogens encountered in greatest volume include oxygen, nitrogen, argon and carbon dioxide. Their physical properties are summarized in Table 8.4.

## Liquid oxygen

Liquid oxygen is pale blue, slightly heavier than water, magnetic, non-flammable and does not produce toxic or irritating vapours. On contact with reducing agents, liquid oxygen can cause explosions.

**Table 8.3 General precautions with cryogenic materials**


---

Obtain authoritative advice from the supplier.

Select storage/service materials and joints with care, allowing for the reduction in ductility at cryogenic temperatures.  
Provide special relief devices as appropriate.

Materials of construction must be scrupulously clean, free of grease etc.

Use only labelled, insulated containers designed for cryogenics, i.e. capable of withstanding rapid changes and extreme differences in temperature, and fill them slowly to minimize thermal shock.

Keep capped when not in use and check venting.

Glass Dewar flasks for small-scale storage should be in metal containers, and any exposed glass taped to prevent glass fragments flying in the event of fracture/implosion.

Large-scale storage containers are usually of metal and equipped with pressure-relief systems.

In the event of faults developing (as indicated by high boil-off rates or external frost), cease using the equipment.

Provide a high level of general ventilation taking note of density and volume of gas likely to develop: initially gases will slump, while those less dense than air (e.g. hydrogen, helium) will eventually rise.

Do not dispose of liquid in a confined area.

Prevent contamination of fuel by oxidant gases/liquids.

With flammable gases, eliminate all ignition sources (refer to Chapter 6). Possibly provide additional high/low level ventilation; background gas detectors to alarm, e.g. at 40% of the LEL. With toxic gases, possibly provide additional local ventilation; monitors connected to alarms; appropriate air-fed respirators. (The flammable/toxic gas detectors may be linked to automatic shutdown instrumentation.)

Limit access to storage areas to authorized staff knowledgeable in the hazards, position of valves and switches.

Display emergency procedures.

Wear face shields and impervious dry gloves, preferably insulated and of loose fit.

Wear protective clothing which avoids the possibility of cryogenic liquid becoming trapped near the skin: avoid turnups and pockets and wear trousers over boots, not tucked in.

Remove bracelets, rings, watches etc. to avoid potential traps of cryogen against skin.

Prior to entry into large tanks containing inert medium, ensure that pipes to the tank from cryogen storage are blanked off or positively closed off: purge with air and check oxygen levels.

If in doubt, provide air-fed respirators and follow the requirements for entry into confined spaces (Chapter 13).

First aid measures include:

Move casualties becoming dizzy or losing consciousness into fresh air and provide artificial respiration if breathing stops.

Obtain medical attention (Chapter 13).

In the event of 'frost-bite' do not rub the affected area but immerse rapidly in warm water and maintain general body warmth.

Seek medical aid.

Ensure that staff are trained in the hazards and precautions for both normal operation and emergencies.

---

Gaseous oxygen is colourless, odourless and tasteless. It does not burn but supports combustion of most elements. Thus upon vaporization liquid oxygen can produce an atmosphere which enhances fire risk; flammability limits of flammable gases and vapours are widened and fires burn with greater vigour. It may cause certain substances normally considered to be non-combustible, e.g. carbon steel, to inflame. In addition to the general precautions set out in Table 8.3, the following are also relevant to the prevention of fires and explosions:

Prohibit smoking or other means of ignition in the area.

Avoid contact with flammable materials (including solvents, paper, oil, grease, wood, clothing) and reducing agents. Thus oil or grease must not be used on oxygen equipment.

Purge oxygen equipment with oil-free nitrogen or oil-free air prior to repairs.

Post warning signs.

In the event of fire, evacuate the area and if possible shut off oxygen supply. Extinguish with

**Table 8.4 Physical properties of selected cryogenic liquids**

| <i>Property of liquid</i>                                           |                   | <i>Oxygen</i> | <i>Nitrogen</i> | <i>Argon</i> | <i>Carbon dioxide</i> |
|---------------------------------------------------------------------|-------------------|---------------|-----------------|--------------|-----------------------|
| Molecular weight                                                    |                   | 32            | 28              | 40           | 44                    |
| Boiling point<br>(at atmospheric pressure)                          | C                 | −183          | −196            | −186         | −78                   |
| Freezing point                                                      | C                 | −219          | −210            | −190         | —                     |
| Critical temperature                                                | K                 | 154.8         | 126.1           | 150.7        | —                     |
| Density of liquid<br>(at atmospheric pressure)                      | kg/m <sup>3</sup> | 1141          | 807             | 1394         | 1562<br>(solid)       |
| Density of vapour<br>(at NBP)                                       | kg/m <sup>3</sup> | 4.43          | 4.59            | 5.70         | 2.90                  |
| Density of dry gas at 15 C<br>and at atmospheric pressure           | kg/m <sup>3</sup> | 1.34          | 1.17            | 1.67         | 1.86                  |
| Latent heat of vaporization at NBP<br>and atmospheric pressure      | kJ/kg             | 214           | 199             | 163          | 151                   |
| Expansion ratio (liquid to gas at<br>15 C and atmospheric pressure) |                   | 842           | 682             | 822          | 538 <sup>(1)</sup>    |
| Volume per cent in dry air                                          | %                 | 20.95         | 78.09           | 0.93         | 0.03                  |

NBP Normal boiling point

<sup>(1)</sup>From liquid CO<sub>2</sub> at 21 bar −18 C.

water spray unless electrical equipment is involved, when carbon dioxide extinguishers should be used.

## Liquid nitrogen and argon

Liquid nitrogen is colourless and odourless, slightly lighter than water and non-magnetic. It does not produce toxic or irritating vapours. Liquid argon is also colourless and odourless but significantly heavier than water. Gaseous nitrogen is colourless, odourless and tasteless, slightly soluble in water and a poor conductor of heat. It does not burn or support combustion, nor readily react with other elements. It does, however, combine with some of the more active metals, e.g. calcium, sodium and magnesium, to form nitrides. Gaseous argon is also colourless, odourless and tasteless, very inert and does not support combustion.

The main hazard from using these gases stems from their asphyxiant nature. In confined, unventilated spaces small leakages of liquid can generate sufficient volumes of gas to deplete the oxygen content to below life-supporting concentrations: personnel can become unconscious without warning symptoms (Chapter 5). Gas build-up can occur when a room is closed overnight.

Also, because the boiling points of these cryogenic liquids are lower than that of oxygen, if exposed to air they can cause oxygen to condense preferentially, resulting in hazards similar to those of liquid oxygen.

## Liquid carbon dioxide

Liquid carbon dioxide is usually stored under 20 bar pressure at −18 C. Compression and cooling of the gas between the temperature limits at the ‘triple point’ and the ‘critical point’ will cause it

to liquefy. The triple point is the pressure temperature combination at which carbon dioxide can exist simultaneously as gas, liquid and solid. Above the critical temperature point of 31 °C it is impossible to liquefy the gas by increasing the pressure above the critical pressure of 73 bar. Reduction in the temperature and pressure of liquid below the triple point causes the liquid to disappear, leaving only gas and solid. (Solid carbon dioxide is also available for cryogenic work and at –78 °C the solid sublimates at atmospheric pressure.)

Liquid carbon dioxide produces a colourless, dense, non-flammable vapour with a slightly pungent odour and characteristic acid ‘taste’. Physical properties are given in Table 8.5 (see also page 277). Figure 8.1 demonstrates the effect of temperature on vapour pressure.

**Table 8.5 Physical properties of carbon dioxide**

|                                                   |                                                  |
|---------------------------------------------------|--------------------------------------------------|
| Molecular weight                                  | 44.01                                            |
| Vapour pressure at 21 °C                          | 57.23 bar                                        |
| Specific volume at 21 °C, 1 atm                   | 547 ml/g                                         |
| Sublimation point at 1 atm                        | – 78.5 °C                                        |
| Triple point at 5.11 atm                          | – 56.6 °C                                        |
| Density, gas at 0 °C, 1 atm                       | 1.977 g/l                                        |
| Specific gravity, gas at 0 °C,<br>1 bar (air = 1) | 1.521                                            |
| Critical temperature                              | 31 °C                                            |
| Critical pressure                                 | 73.9 bar                                         |
| Critical density                                  | 0.468 g/ml                                       |
| Latent heat of vaporization<br>at triple point    | 83.2 cal/g                                       |
| at 0 °C                                           | 56.2 cal/g                                       |
| Specific heat, gas at 25 °C, 1 atm                |                                                  |
| $C_p$                                             | 0.205 cal/g °C                                   |
| $C_v$                                             | 0.1565 cal/g °C                                  |
| ratio $C_p/C_v$                                   | 1.310                                            |
| Thermal conductivity at 0 °C                      | $3.5 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| at 100 °C                                         | $5.5 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Viscosity, gas at 21 °C, 1 atm                    | 0.0148 cP                                        |
| Entropy, gas at 25 °C, 1 atm                      | 1.160 cal/g °C                                   |
| Heat of formation, gas at 25 °C                   | – 2137.1 cal/g                                   |
| Solubility in water at 25 °C, 1 atm               | 0.759 vol/vol water                              |

Inhalation of carbon dioxide causes the breathing rate to increase (Table 8.6): 10% CO<sub>2</sub> in air can only be endured for a few minutes; at 25% death can result after a few hours exposure.

The 8 hr TWA hygiene standard (see Chapter 5) for carbon dioxide is 0.5%; at higher levels life may be threatened by extended exposure. The following considerations therefore supplement those listed in Table 8.3:

Ensure that operator exposure is below the hygiene standard. (Note: For environmental monitoring, because of its toxicity, a CO<sub>2</sub> analyser must be used as distinct from simply relying on checks of oxygen levels.)

When arranging ventilation, remember that the density of carbon dioxide gas is greater than that of air.

Ensure that pipework and control systems are adequate to cope with the pressures associated with storage and conveyance of carbon dioxide, which are higher than those encountered with most other cryogenic liquids.

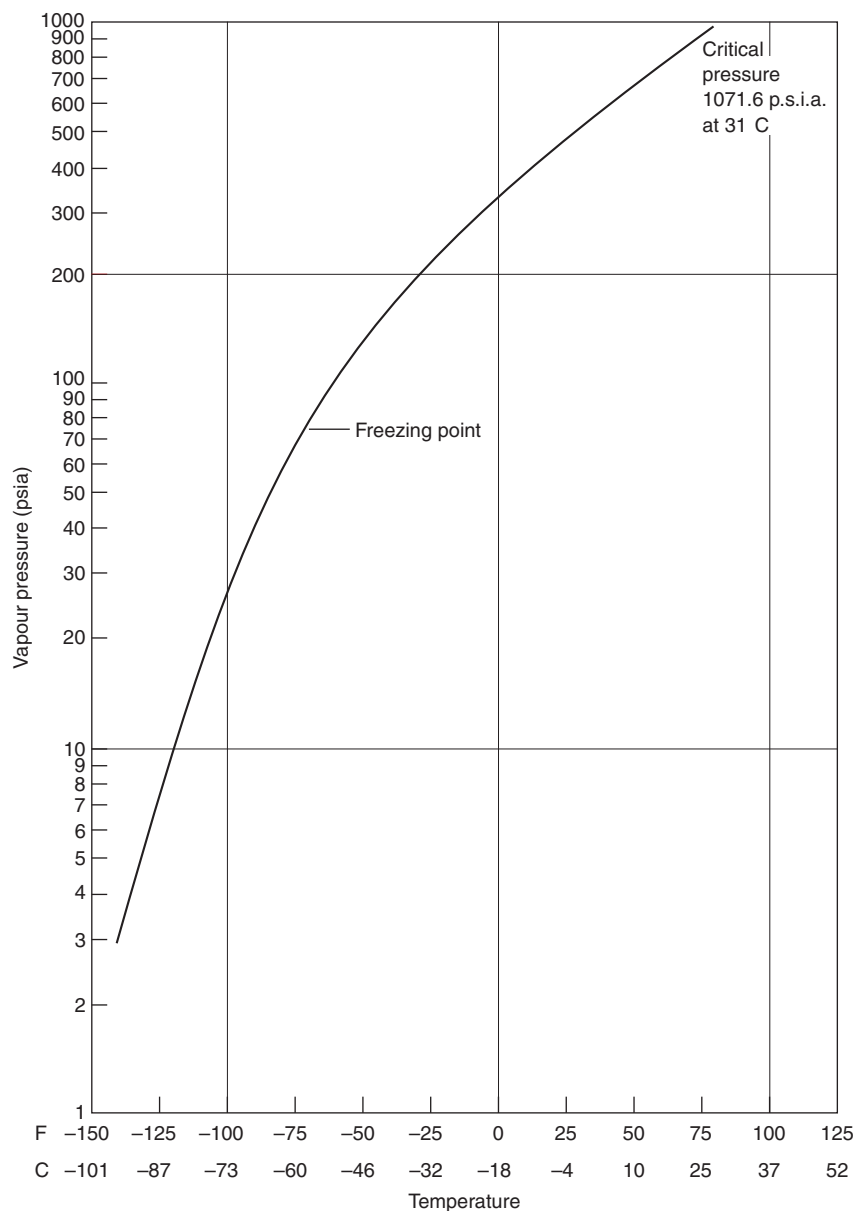


Figure 8.1 Carbon dioxide vapour pressure versus temperature

## Liquefied natural gas

Liquefied natural gas is predominantly methane. The cryogenic properties of methane are:

|                                  |          |
|----------------------------------|----------|
| Boiling point                    | -162 C   |
| Critical temperature             | -82 C    |
| Critical pressure                | 45.7 atm |
| Liquid-to-gas ratio<br>by volume | 1 to 637 |

**Table 8.6 Effect of carbon dioxide exposure on breathing rates**

| <i>CO<sub>2</sub> in air (vol. %)</i> | <i>Increased lung ventilation</i>          |
|---------------------------------------|--------------------------------------------|
| 0.1–1                                 | slight, unnoticeable                       |
| 2                                     | 50% increase                               |
| 3                                     | 100% increase                              |
| 5                                     | 300% increase; breathing becomes laborious |

The impurities in LNG result in slightly different properties, and there are significant variations depending upon its source of supply.

Natural gas is considered non-toxic but can produce an oxygen deficient atmosphere (p. 153). It is odourless (therefore an odorant is added for distribution by pipeline). Its physical properties are similar to those of methane, i.e.:

|                      |           |
|----------------------|-----------|
| Ignition temperature | 537 C     |
| Flammable limits     | 5% to 15% |
| Vapour density       | 0.55      |

However, the safety considerations with LNG must account for:

The tendency, for economic reasons, to store it in very large insulated containers.

The requirement for special materials of construction to cater for storage at –162 C, and for design of plant to cope with thermal differences.

The prevention of leaks, since liquid may generate large quantities of flammable gas.

The addition of odorants after vaporization, i.e. the liquid is odour-free.

The gas generated by vaporization is cold and therefore denser than air, i.e. it tends to slump.

LPG and methane are discussed further in Chapter 9.

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# Compressed gases

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Whilst gases are sometimes prepared *in situ* for cost and safety reasons (e.g. to remove the risk associated with their transport, storage and piping to point of use) they are more often stored on an industrial scale at low pressure, either under refrigerated conditions, e.g. cryogenics (Chapter 8), or at ambient temperature in ‘gasholders’, which ‘telescope’ according to the quantity of gas and are fitted with water or oil seals to prevent gas escape. Smaller quantities of gas at high pressure are usually stored in bottle-shaped gas cylinders. They find widespread use in welding, fuel for gas burners, hospitals, laboratories etc. The construction of compressed gas cylinders ensures that, when first put into service, they are safe for their designated use. Serious accidents can, however, result from ignorance of the properties of the gases, or from misuse or abuse. Great care is needed during the transportation, handling, storage and disposal of such cylinders.

Compressed gases can often be more dangerous than chemicals in liquid or solid form because of the potential source of high energy, low boiling-point of some liquid contents resulting in the potential for flashing (page 50), ease of diffusion of escaping gas, low flashpoint of some highly flammable liquids, and the absence of visual and/or odour detection of some leaking materials. The containers also tend to be heavy and bulky.

Compressed gases, therefore, present a unique hazard from their potential physical and chemical dangers. Unless cylinders are secured they may topple over, cause injury to operators, become damaged themselves and cause contents to leak. If the regulator shears off, the cylinder may rocket like a projectile or ‘torpedo’ dangerously around the workplace. Other physical hazards stem from the high pressure of a cylinder’s contents, e.g. accidental application of a compressed gas/air hose or jet into eyes or onto an open cut or wound, whereby the gas can enter the tissue or bloodstream, is particularly dangerous.

A further hazard exists when compressed air jets are used to clean machine components in workplaces: flying particles have caused injury and blindness. Cylinders may fail if over-pressurized or weakened by the application of heat. Liquefied gases, e.g. butane or propane, respond more rapidly to heat than the permanent gases such as nitrogen or oxygen. Cylinders are normally protected by pressure relief valves, fusible plugs or bursting discs.

Low boiling-point materials can cause frostbite on contact with living tissue. While this is an obvious hazard with cryogenics, e.g. liquid nitrogen or oxygen, cylinders of other liquefied gases also become extremely cold and covered in ‘frost’ as the contents are discharged (page 47).

Precautions also have to be instituted to protect against the inherent properties of the cylinder contents, e.g. toxic, corrosive, flammable (refer to Table 9.1). Most gases are denser than air; common exceptions include acetylene, ammonia, helium, hydrogen and methane. Even these may on escape be much cooler than ambient air and therefore slump initially. Eventually the gas will rise and accumulate at high levels unless ventilated. Hydrogen and acetylene, which both have very wide flammable limits (Table 6.1), can form explosive atmospheres in this way.

More dense gases will on discharge accumulate at low levels and may, if flammable, travel a considerable distance to a remote ignition source.



**Table 9.1 Compressed gases: hazards and construction materials for services**

| Gas                    | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                                                                                                                  |                                                                                 |
|------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
|                        |                       | Compatible                                                                                                                                                                                                       | Incompatible                                                                    |
| Acetylene              | F                     | Stainless steel, aluminium, wrought iron                                                                                                                                                                         | Unalloyed copper, alloys containing >70% copper, silver, mercury, and cast iron |
| Air                    | O                     | Any common metal or plastic                                                                                                                                                                                      |                                                                                 |
| Allene                 | F                     | Mild steel, aluminium, brass, or stainless steel                                                                                                                                                                 | Copper, silver and their alloys, PVC and neoprene                               |
| Ammonia                | C F T                 | Iron and steel                                                                                                                                                                                                   | Copper, zinc, tin and their alloys (e.g. brass), and mercury                    |
| Argon                  |                       | Any common metal                                                                                                                                                                                                 |                                                                                 |
| Arsine                 | F T                   | Stainless steel and iron                                                                                                                                                                                         |                                                                                 |
| Boron trichloride      | C T                   | Any common metal for dry gas<br>Copper, Monel, Hastelloy B, PVC, polythene and PTFE if <i>moist</i> gas is used                                                                                                  | Any metal incompatible with hydrochloric acid when moist gas is used            |
| Boron trifluoride      | C T                   | Stainless steel, copper, nickel, Monel, brass, aluminium for <i>dry</i> gas ≤200 C. Borosilicate glass for low pressures. For <i>moist</i> gas, copper and polyvinylidene chloride plastics                      | Rubber, nylon, phenolic resins, cellulose and commercial PVC                    |
| Bromine pentafluoride  | C T O                 | Monel and nickel                                                                                                                                                                                                 |                                                                                 |
| Bromine trifluoride    | C T O                 | Monel and nickel                                                                                                                                                                                                 |                                                                                 |
| Bromotrifluoroethylene | F T                   | Most common metals so long as gas is dry                                                                                                                                                                         | Magnesium alloys and aluminium containing >2% magnesium                         |
| Bromotrifluoromethane  |                       | Most common metals                                                                                                                                                                                               |                                                                                 |
| 1,3-Butadiene          | F T                   | Mild steel, aluminium, brass, copper or stainless steel                                                                                                                                                          | PVC and Neoprene plastic                                                        |
| Butane                 | F                     | Any common metal                                                                                                                                                                                                 |                                                                                 |
| 1, Butene              | F                     | Any common metal                                                                                                                                                                                                 |                                                                                 |
| Carbon dioxide         | T                     | Iron, steel, copper, brass, plastic for dry gas. For moist gas use stainless steel or certain plastics                                                                                                           | For moist gas avoid materials attacked by acids                                 |
| Carbon monoxide        | F T                   | Copper-lined metals for pressures <34 bar. Certain highly alloyed chrome steels                                                                                                                                  | Iron, nickel and certain other metals at high pressures                         |
| Carbon tetrafluoride   |                       | Any common metal                                                                                                                                                                                                 |                                                                                 |
| Carbonyl fluoride      | C F T                 | Steel, stainless steel, copper or brass for dry gas.<br>Monel, copper or nickel for moist gas                                                                                                                    |                                                                                 |
| Carbonyl sulphide      | F T                   | Aluminium and stainless steel                                                                                                                                                                                    |                                                                                 |
| Chlorine               | C T O                 | Extra heavy black iron or steel for dry gas. Drop forged steel, PTFE tape. Moist gas requires glass, stoneware (for low pressures) and noble metals. High silica, iron, Monel and Hastelloy show some resistance | Rubber (e.g. gaskets)                                                           |

Table 9.1 Cont'd

| Gas                           | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                                                           |                                                                                                                                                                           |
|-------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               |                       | Compatible                                                                                                                                                | Incompatible                                                                                                                                                              |
| Chlorine trifluoride          | C T O                 | Monel and nickel, PTFE and Kel-F, soft copper, 2S aluminium and lead are suitable for gaskets                                                             |                                                                                                                                                                           |
| Chlorodifluoromethane         |                       | Steel, cast iron, brass, copper, tin, lead, aluminium at normal conditions<br>Neoprene or chloroprene rubber and pressed fabrics are suitable for gaskets | Silver, brass, aluminium, steel, copper, nickel can cause decomposition at elevated temperatures. Magnesium alloys and aluminium containing >2% magnesium. Natural rubber |
| Chloropentafluoroethane       |                       | Neoprene or chloroprene rubber and pressed fabrics are suitable for gaskets                                                                               | Silver, brass, aluminium, steel, copper, nickel can cause decomposition at elevated temperatures. Magnesium alloys and aluminium containing >2% magnesium. Natural rubber |
| Chlorotrifluoroethane         | F T                   | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Chlorotrifluoromethane        |                       | As for chlorodifluoromethane                                                                                                                              |                                                                                                                                                                           |
| Cyanogen                      | F T                   | Stainless steel, Monel and Inconel ≤65 °C. Glass-lined equipment. Iron and steel at ordinary temperatures                                                 |                                                                                                                                                                           |
| Cyanogen chloride             | C T                   | Common metals for dry gas. Monel, tantalum. Glass for moist gas                                                                                           |                                                                                                                                                                           |
| Cyclobutane                   | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Cyclopropane                  | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Deuterium                     | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Diborane                      | F T                   | Most common metals. Polyvinylidene chloride, polyethylene, Kel-F PTFE graphite and silicone vacuum grease                                                 | Rubber and certain hydrocarbon lubricants                                                                                                                                 |
| Dibromodifluoromethane        |                       | Copper or stainless steel                                                                                                                                 | Aluminium for wet gas                                                                                                                                                     |
| 1,2-Dibromotetrafluoroethane  | C                     | Most common metals for dry gas. Stainless steel, titanium and nickel for moist gas                                                                        | Zinc                                                                                                                                                                      |
| Dichlorodifluoromethane       |                       | As for chlorodifluoromethane                                                                                                                              |                                                                                                                                                                           |
| Dichlorofluoromethane         |                       | As for chlorodifluoromethane                                                                                                                              |                                                                                                                                                                           |
| Dichlorosilane                | C F T                 | Nickel and nickel steels and PTFE                                                                                                                         | Stainless steel for moist gas                                                                                                                                             |
| 1,2-Dichlorotetrafluoroethane |                       | As for chlorodifluoromethane                                                                                                                              |                                                                                                                                                                           |
| 1,1-Difluoro-1-chloroethane   | F                     | Most common metals under normal conditions                                                                                                                | Hot metals can cause degradation to toxic corrosive products                                                                                                              |
| 1,1-Difluoroethane            | F                     | Most common metals under normal conditions                                                                                                                | Hot metals can cause degradation to toxic corrosive products                                                                                                              |
| 1,1-Difluoroethylene          | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Dimethylamine                 | C F T                 | Iron and steel                                                                                                                                            | Copper, tin, zinc, and their alloys                                                                                                                                       |
| Dimethyl ether                | F T                   | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| 2,2-Dimethyl propane          | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Ethane                        | F                     | Most common metals                                                                                                                                        |                                                                                                                                                                           |
| Ethyl acetylene               | F                     | Steel and stainless steel                                                                                                                                 | Copper, other metals capable of forming explosive acetylides                                                                                                              |

Table 9.1 Cont'd

| Gas                 | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                                                                                                                                                                                |                                                                            |
|---------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
|                     |                       | Compatible                                                                                                                                                                                                                                                                     | Incompatible                                                               |
| Ethyl chloride      | F T                   | Most materials for dry gases                                                                                                                                                                                                                                                   |                                                                            |
| Ethylene            | F                     | Any common metal                                                                                                                                                                                                                                                               |                                                                            |
| Ethylamine          | C F T                 | Iron and steel. Reinforced neoprene hose                                                                                                                                                                                                                                       | Copper, tin, zinc and their alloys                                         |
| Ethylene oxide      | F T                   | Properly grounded steel                                                                                                                                                                                                                                                        | Copper, silver, magnesium and their alloys                                 |
| Fluorine            | C T O                 | Brass, iron, aluminium, magnesium and copper at normal temperatures. Nickel and Monel at higher temperatures                                                                                                                                                                   |                                                                            |
| Fluoroform          |                       | Any common metal                                                                                                                                                                                                                                                               |                                                                            |
| Germane             | F T                   | Iron and steel                                                                                                                                                                                                                                                                 |                                                                            |
| Helium              |                       | Any common metal                                                                                                                                                                                                                                                               |                                                                            |
| Hexafluoroacetone   | C T                   | For dry gas Monel, nickel, Inconel, stainless steel, copper and glass – Hastelloy C-line equipment                                                                                                                                                                             |                                                                            |
| Hexafluoroethane    |                       | Any common metal for normal temperatures. Copper, stainless steel and aluminium ≤150 C                                                                                                                                                                                         |                                                                            |
| Hexafluoropropylene |                       | Any common metal for dry gas                                                                                                                                                                                                                                                   |                                                                            |
| Hydrogen            | F                     | Most common metals for normal use                                                                                                                                                                                                                                              | At elevated temperature and pressure hydrogen embrittlement can result     |
| Hydrogen bromide    | C T                   | Most common metals when dry. Silver, platinum and tantalum for moist gas. Heavy black iron for high-pressure work. High-pressure steel, Monel or aluminium pipe.                                                                                                               | Most metals when gas is moist. Galvanized pipe or brass or bronze fittings |
| Hydrogen chloride   | C T                   | Stainless steel, mild steel for normal conditions of temperature and pressure. When moist use silver, platinum or tantalum. Moist or dry gas use backed carbon, graphite. High pressure work in heavy black iron pipework. High pressure Monel or aluminium iron bronze valves | Galvanized pipes or brass or bronze fittings                               |
| Hydrogen cyanide    | F T                   | Low-carbon steel at normal temp. and stainless steel for higher temperatures                                                                                                                                                                                                   |                                                                            |
| Hydrogen fluoride   | C T                   | Steel in the absence of sulphur dioxide contaminants in the gas and at temperatures <65 C. Monel, Inconel, nickel and copper for liquid or gas at elevated temperature                                                                                                         | Cast iron or malleable fittings                                            |
| Hydrogen iodide     | C T                   | Stainless steel, mild steel under normal temperature and pressure                                                                                                                                                                                                              | Moist gas corrodes most metals                                             |

Table 9.1 Cont'd

| Gas                   | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                                                                              |                                                                                     |
|-----------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|                       |                       | Compatible                                                                                                                                                                   | Incompatible                                                                        |
|                       |                       | Silver, platinum and tantalum, carbon, graphite for wet gas. At higher pressures use extra heavy black iron pipe. High-pressure steel, Monel or aluminium-iron-bronze valves | Galvanized pipe or brass or bronze fittings                                         |
| Hydrogen selenide     | F T                   | Aluminium and stainless steel are preferred but iron, steel or brass are acceptable                                                                                          |                                                                                     |
| Hydrogen sulphide     | F T                   | Aluminium preferred. Iron and steel are satisfactory. Brass, though tarnished, is acceptable                                                                                 | Many metals in the presence of moist gas                                            |
| Isobutane             | F                     | Most common metals                                                                                                                                                           |                                                                                     |
| Isobutylene           | F                     | Most common metals                                                                                                                                                           |                                                                                     |
| Krypton               |                       | Most common metals                                                                                                                                                           |                                                                                     |
| Methane               | F                     | Most common metals                                                                                                                                                           |                                                                                     |
| Methyl acetylene      | F                     | Most common metals                                                                                                                                                           | Copper, silver, mercury and their alloys                                            |
| Methylamine           | C F T                 | Iron and steel                                                                                                                                                               | Copper, tin, zinc and their alloys. Avoid mercury                                   |
| Methyl bromide        | C F T                 | Most common metals when dry                                                                                                                                                  | Aluminium and its alloys                                                            |
| 3-Methyl-1-butane     | F                     | Most common metals                                                                                                                                                           |                                                                                     |
| Methyl chloride       | F T                   | Most common metals when dry                                                                                                                                                  | Zinc, magnesium rubber and neoprene particularly when moist. Aluminium is forbidden |
| Methyl fluoride       | F T                   | Most common metals                                                                                                                                                           |                                                                                     |
| Methyl mercaptan      | F T                   | Stainless steel and copper-free steel alloys and aluminium. Iron and steel for dry gas                                                                                       |                                                                                     |
| Methyl vinyl ether    | F                     | Most common metals                                                                                                                                                           | Copper and its alloys                                                               |
| Neon                  |                       | Most common metals                                                                                                                                                           |                                                                                     |
| Nickel carbonyl       | F T                   | Most common metals for pure gas. Copper or glass-lined equipment for carbonyl in the presence of carbon monoxide                                                             |                                                                                     |
| Nitric oxide          | T O                   | Most common metals for dry gas. For moist gas use 18:8 stainless steel, PTFE                                                                                                 |                                                                                     |
| Nitrogen              |                       | Any common metal                                                                                                                                                             |                                                                                     |
| Nitrogen dioxide      | C T O                 | Most common metals for dry gas. For moist gas use 18:8 stainless steel                                                                                                       |                                                                                     |
| Nitrogen trifluoride  | T O                   | Nickel and Monel are preferred. Steel, copper and glass are acceptable at ordinary temperatures                                                                              | Plastics                                                                            |
| Nitrogen trioxide     | C T O                 | Steel for dry gas otherwise use 18:8 stainless steel                                                                                                                         |                                                                                     |
| Nitrosyl chloride     | C T O                 | Nickel, Monel and Inconel. For moist gas tantalum is suitable                                                                                                                |                                                                                     |
| Nitrous oxide         | O                     | Most common metals                                                                                                                                                           |                                                                                     |
| Octafluorocyclobutane | T                     | Cast iron and stainless steel <120 C, steel ≤175 C, Inconel, nickel and platinum ≤400 C                                                                                      | Avoid the metals opposite >500 C                                                    |
| Oxygen                | O                     | Most common metals                                                                                                                                                           | On grease or combustible                                                            |

Table 9.1 Cont'd

| Gas                      | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                                    |                                                                                                                                                                                                                   |
|--------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                          |                       | Compatible                                                                                                                         | Incompatible                                                                                                                                                                                                      |
| Oxygen difluoride        | T O                   | Glass, stainless steel, copper, Monel or nickel ≤200 C. At higher temperatures only nickel and Monel are recommended               | materials                                                                                                                                                                                                         |
| Ozone                    | F T O                 | Glass, stainless steel, Teflon, Hypalon, aluminium, Tygon, PVC and polythene                                                       | Copper and its alloys, rubber or any composition thereof, oil, grease or readily combustible material                                                                                                             |
| Perchloryl fluoride      | T                     | Most metals and glass for dry gas at ordinary temperatures                                                                         | Many gasket materials are embrittled<br>At higher temperatures many organic materials and some metals can be ignited<br>Some metals such as titanium show deflagration in contact with the gas under severe shock |
| Perfluorobutane          | C T                   | Most common materials                                                                                                              |                                                                                                                                                                                                                   |
| Perfluorobutene          |                       | Most common materials when dry                                                                                                     |                                                                                                                                                                                                                   |
| Perfluoropropane         |                       | Most common metals                                                                                                                 |                                                                                                                                                                                                                   |
| Phosgene                 |                       | Common metals for dry gas. Monel, tantalum or glass lined equipment for moist gas                                                  |                                                                                                                                                                                                                   |
| Phosphine                | F T                   | Iron or steel                                                                                                                      |                                                                                                                                                                                                                   |
| Phosphorus pentafluoride | F T                   | Steel, nickel, Monel and Pyrex for dry gas. For moist gas hard rubber and paraffin wax                                             |                                                                                                                                                                                                                   |
| Phosphorus trifluoride   |                       | Steel, nickel, Monel and the more noble metals and Pyrex for dry gas                                                               |                                                                                                                                                                                                                   |
| Propane                  | F                     | Most common metals                                                                                                                 |                                                                                                                                                                                                                   |
| Propylene                | F                     | Most common metals                                                                                                                 |                                                                                                                                                                                                                   |
| Propylene oxide          | F T                   | Steel or stainless steel preferred though copper and brass are suitable for acetylene-free gas. PTFE gaskets                       | Rubber                                                                                                                                                                                                            |
| Silane                   | F T                   | Iron, steel, copper, brass                                                                                                         |                                                                                                                                                                                                                   |
| Silicone tetrafluoride   | C T                   | Most common metals for the dry gas. Steel, Monel and copper for moist gas                                                          |                                                                                                                                                                                                                   |
| Sulphur dioxide          | C T O                 | Most common metals for dry gas. Lead, carbon, aluminium and stainless steel for moist gas                                          | Zinc                                                                                                                                                                                                              |
| Sulphur hexafluoride     |                       | Most common metals. Copper, stainless steel and aluminium are resistant to the decomposition products at 150 C                     |                                                                                                                                                                                                                   |
| Sulphur tetrafluoride    | C T                   | Stainless steel or 'Hastelloy C' lined containers. Glass suitable for short exposures if dry. 'Tygon' for low-pressure connections | Glass for moist gas                                                                                                                                                                                               |
| Sulphuryl fluoride       | T                     | Any common metal at normal temperatures and pressures                                                                              | Some metals at elevated temperatures                                                                                                                                                                              |
| Tetrafluoroethylene      | F                     | Most common metals                                                                                                                 |                                                                                                                                                                                                                   |

**Table 9.1 Cont'd**

| Gas                                   | Hazard <sup>(1)</sup> | Materials of construction for ancillary services <sup>(2)</sup>                                                 |                                                                                                                |
|---------------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
|                                       |                       | Compatible                                                                                                      | Incompatible                                                                                                   |
| Tetrafluorohydrazine                  | T O                   | Glass, stainless steel, copper or nickel to temperatures of 200 C. For higher temperatures use nickel and Monel |                                                                                                                |
| Trichlorofluoromethane                | T                     | Steel, cast iron, brass, copper, tin, lead, aluminium under normal, dry conditions                              | Some of the opposite at high temperatures magnesium alloys and aluminium coating >2% magnesium. Natural rubber |
| 1,1,2-Trichloro-1,2,2-trifluoroethane |                       | As above                                                                                                        | As above                                                                                                       |
| Trimethylamine                        | C F T                 | Iron, steel, stainless steel and Monel. Rigid steel piping                                                      | Copper, tin, zinc and most of their alloys                                                                     |
| Vinyl bromide                         | F T                   | Steel                                                                                                           | Copper and its alloys                                                                                          |
| Vinyl chloride                        | C F T                 | Steel                                                                                                           | Copper and its alloys                                                                                          |
| Vinyl fluoride                        | F                     | Steel                                                                                                           | Copper and its alloys                                                                                          |
| Xenon                                 |                       | Most common materials                                                                                           |                                                                                                                |

C Corrosive  
 F Flammable  
 T Toxic  
 O Oxidizing

<sup>(1)</sup> Even non-toxic gases are potentially hazardous owing to asphyxiation (oxygen deficiency). Irrespective of material, all equipment must be adequately designed to withstand process pressures.

<sup>(2)</sup> This is a guide and is no substitute for detailed literature.

To prevent interchange of fittings between cylinders of combustible and non-combustible gases, the valve outlets are screwed left-hand and right-hand thread, respectively (Table 9.2). Primary identification is by means of labelling with the name and chemical formula on the shoulder of the cylinder. Secondary identification is by use of ground colours on the cylinder body. Unless specified in Table 9.2, gas and gas mixtures shall be identified by a colour classification indicating gas properties in accordance with the risk diamond on the cylinder label e.g.

|                                                                   |              |
|-------------------------------------------------------------------|--------------|
| Toxic and/or corrosive                                            | Yellow       |
| Flammable                                                         | Red          |
| Oxidizing                                                         | Light blue   |
| Inert (non-toxic, non-corrosive,<br>non-flammable, non-oxidizing) | Bright green |

The full scheme is given in BS EN 1089-3: 1997.

This should be consulted for the colour coding of gas mixtures used for inhalation e.g. medical and breathing apparatus mixtures containing oxygen.

**Table 9.2 Specific colour codes for selected compressed gases**

| Gas            | Colour     |
|----------------|------------|
| Acetylene      | Maroon     |
| Argon          | Dark green |
| Carbon dioxide | Grey       |
| Helium         | Brown      |
| Oxygen         | White      |
| Nitrogen       | Black      |
| Nitrous oxide  | Blue       |

Table 9.3 provides general guidance for handling compressed gases.

**Table 9.3 General precautions for handling compressed gases**

Consult the supplier for data on the specification, properties, handling advice and on suitable service materials for individual gases.

### **Storage**

Segregate according to hazard.

Stores should be adequately ventilated and, ideally, located outside and protected from the weather.

Store away from sources of heat and ignition.

Cylinders within workplaces should be restricted to those gases in use. Specially designed compartments with partitions may be required to protect people in the event of explosion. Take into account emergency exits, steam or hot water systems, the proximity of other processes etc. Consider the possibility of dense gases accumulating in drains, basements, cable ducts, lift shafts etc.

Where necessary, provide fireproof partitions/barriers to separate/protect cylinders.

Protect from mechanical damage.

All cylinders must be properly labelled and colour coded (BS 349).

Store full and empty cylinders separately.

Use in rotation: first in, first out.

Restrict access to the stores to authorized staff.

Display 'No smoking' and other relevant warning signs.

Ensure that all staff are fully conversant with the correct procedures when using pressure regulators. (For cylinders without handwheel valves, the correct cylinder valve keys should be kept readily available, e.g. on the valve. Only use such keys.

Do not extend handles or keys to permit greater leverage; do not use excessive force, e.g. hammering, when opening/closing valves or connecting/disconnecting fittings. The pressure regulator must be fully closed before opening the cylinder valve. This valve can then be opened slowly until the regulator gauge indicates the cylinder pressure but should not be opened wider than necessary. The pressure regulator can then be opened to give the required delivery pressure.

When a cylinder is not in use, or is being moved, the cylinder valve must be shut. When a cylinder has been connected, the valve should be opened with the regulator closed; joints should then be tested with soap/detergent solution.)

Clearly and permanently mark pressure gauges for use on oxygen. Do not contaminate them with oil or grease or use them for other duties.

Cylinders that cannot be properly identified should not be used; do not rely on colour code alone.

Never try to refill cylinders.

Never use compressed gas to blow away dust or dirt.

Provide permanent brazed or welded pipelines from the cylinders to near the points of gas use. Select pipe materials suitable for the gas and its application. Any flexible piping used should be protected against physical damage. Never use rubber or plastic connections from cylinders containing toxic gases.

On acetylene service, use only approved fittings and regulators. Avoid any possibility of it coming into contact with copper, copper-rich alloys or silver-rich alloys. (In the UK use at a pressure greater than 600 mbar g must be notified to HM Explosives Inspectorate for advice on appropriate standards.)

On carbon dioxide service, rapid withdrawal of gas may result in plugging by solid CO<sub>2</sub>. Close the valve, if possible, to allow the metal to warm up; this will prevent a sudden gas discharge.

Replace the correct caps or guards on cylinder valves when not in use and for return to the supplier.

Test and inspect cylinders and pressure regulators regularly in accordance with current legislation.

Design and manage cylinder stores in accordance with suppliers' recommendations.

Wear appropriate personal protection when entering any store.

Inspect condition of cylinders regularly, especially those containing hazardous gases (e.g. corrosive).

### **Use**

Transport gases in specially designed trolleys and use eye protection, stout gloves (preferably textile or leather) and protective footwear.

Do not roll or drop cylinders off the backs of wagons; never lift cylinders by the cap.

Ideally, depending on the length of pipe run, locate cylinders outside (for hazardous gases, valves installed within the workplace can be used for remote control of the main supply from the cylinder in the event of an emergency). Site cylinders so that they cannot become part of an electrical circuit.

Securely clamp, or otherwise firmly hold in position, cylinders on installation. (Unless otherwise specified, cylinders containing liquefied or dissolved gases must be used upright.)

Avoid subjecting cylinders containing liquid to excessive heat.

Table 9.3 Cont'd

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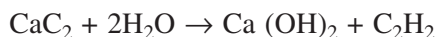
|                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fit approved cylinder pressure regulators, selected to give a maximum pressure on the reduced side commensurate with the required delivery pressure. (The regulator and all fittings upstream of it must be able to withstand at least the maximum cylinder pressure.)                                                            |
| Fit in-line flame arresters for flammable gases and eliminate ignition sources.                                                                                                                                                                                                                                                   |
| Use compatible pipe fittings. (Flammable gas cylinders have valves with left-hand threads; cylinders for oxygen and non-flammable gases, except occasionally helium, have valves with right-hand threads. Certain liquefied gas cylinders have two supply lines, one for gas and one for liquid, dependent on cylinder position.) |
| Do not use oil, grease or joining compounds on any fittings for compressed gas cylinders.                                                                                                                                                                                                                                         |
| Fit an excess flow valve to the outlet of a regulator, selected to allow the maximum required gas flow.                                                                                                                                                                                                                           |
| Use respirators and face protection etc. when changing regulators on cylinders of toxic gases.                                                                                                                                                                                                                                    |
| Turn off gas supply at the cylinder at the end of each day's use.                                                                                                                                                                                                                                                                 |
| Consider the need for gas detection/alarms, e.g. for hazardous gases left in use out of normal hours.                                                                                                                                                                                                                             |
| Periodic checks:                                                                                                                                                                                                                                                                                                                  |
| Ensure no gas discharge when gauge reading is zero                                                                                                                                                                                                                                                                                |
| Ensure reading on gauge does not increase as the regulator valve is closed                                                                                                                                                                                                                                                        |
| Check for 'crawl' due to wear on the regulator valve and seat assembly                                                                                                                                                                                                                                                            |
| Ensure no leak between cylinder and regulator                                                                                                                                                                                                                                                                                     |
| Overhaul regulators on a 3–6 month basis for corrosive gases, annually for others                                                                                                                                                                                                                                                 |
| Train staff in hazards and correct handling procedures.                                                                                                                                                                                                                                                                           |

---

The hazards and safety precautions for selected common compressed gases are discussed below to illustrate the general approach. More details should be sought from suppliers. Some methods for their preparation *in situ* are noted; full experimental details must be obtained from the literature.

## Acetylene

Acetylene is manufactured by the controlled reaction between water and calcium carbide:



Alternatively it is obtained from cracking low molecular-weight aliphatic hydrocarbons, or by the partial oxidation of natural gas.

Because of its high chemical reactivity, acetylene has found wide use in synthesis of vinyl chloride, vinyl acetate, acrylonitrile, vinyl ethers, vinyl acetylene, trichloro- and tetrachloroethylene etc., in oxyacetylene cutting and welding, and as a fuel for atomic absorption instruments.

Acetylene is a simple asphyxiant and anaesthetic. Pure acetylene is a colourless, highly flammable gas with an ethereal odour. Material of commercial purity has an odour of garlic due to the presence of impurities such as phosphine. Its physical properties are shown in Table 9.4. Acetylene, which condenses to a white solid subliming at  $-83^\circ\text{C}$ , is soluble in its own volume of water but highly soluble in acetone.

Under certain conditions acetylene can explode when mixed with air, hydrogen or ethylene.

Accidental heating of a small area of cylinder wall to  $185^\circ\text{C}$  or above may promote an extremely dangerous condition. Violent reactions have occurred between acetylene and oxidants such as oxides of nitrogen (see later), nitric acid, calcium hypochlorite, ozone and halogens. In the free state acetylene can decompose violently, e.g. above 9 psig (0.62 bar) undissolved (free) acetylene will begin to dissociate and revert to its constituent elements. This is an exothermic process which can result in explosions of great violence. For this reason acetylene is transported in acetone contained in a porous material inside the cylinder. Voids in the porous substance can result from settling, e.g. if the cylinder is stored horizontally or through damage to the cylinder in the form of denting. Voids may enable acetylene to decompose, e.g. on initiation by mechanical shock if the cylinder is dropped.



**Table 9.4 Physical properties of acetylene**

|                                                                 |                                                  |
|-----------------------------------------------------------------|--------------------------------------------------|
| Molecular weight                                                | 26.038                                           |
| Vapour pressure of pure liquid at 21 °C (not cylinder pressure) | 43.8 bar                                         |
| Specific volume at 15.6 °C, 1 atm                               | 902.9 ml/g                                       |
| Boiling point at 1.22 atm                                       | -75 °C                                           |
| Sublimation point at 1 atm                                      | -84.0 °C                                         |
| Triple point at saturation pressure                             | -80.8 °C                                         |
| Specific gravity, gas at 15.6 °C, 1 atm (air = 1)               | 0.9057                                           |
| Density, gas at 0 °C, 1 atm                                     | 1.1709 g/l                                       |
| Critical temperature                                            | 36.3 °C                                          |
| Critical pressure                                               | 62.4 bar                                         |
| Critical density                                                | 0.231 g/ml                                       |
| Latent heat of sublimation at -84 °C                            | 193.46 cal/g                                     |
| Latent heat of fusion at triple point                           | 23.04 cal/g                                      |
| Flammable limits in air                                         | 2.5–81.0% by volume                              |
| Auto-ignition temperature                                       | 335 °C                                           |
| Gross heat of combustion at 15.6 °C, 1 atm                      | 13.2 cal/cc                                      |
| Specific heat, gas at 25 °C, 1 atm                              |                                                  |
| $C_p$                                                           | 0.4047 cal/g °C                                  |
| $C_v$                                                           | 0.3212 cal/g °C                                  |
| ratio $C_p/C_v$                                                 | 1.26                                             |
| Thermal conductivity, gas at 0 °C                               | $4.8 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Viscosity, gas at 25 °C, 1 atm                                  | 0.00943 cP                                       |
| Entropy, gas at 25 °C, 1 atm                                    | 1.843 cal/g °C                                   |
| Solubility in water at 0 °C, 1 atm                              | 1.7 vol/vol H <sub>2</sub> O                     |

Figure 9.1 illustrates the rise in cylinder pressure with temperature. Normally, acetylene cylinders are fitted with a fusible metal plug which melts at about 100 °C.

Acetylene can form metal acetylides, such as copper or silver acetylide, which on drying become highly explosive: service materials require careful selection.

In addition to the general precautions for compressed gases in Table 9.3, the following control measures should be considered for acetylene:

Never use free acetylene at pressures above 9 psig (0.62 bar) unless special safety features are employed.

Store and use cylinders only in an upright position.

Store reserves separate from oxygen cylinders.

Ensure that no means of accidental ignition are in the area and provide adequate ventilation.

Consult local regulations for use of this gas.

Ensure that 'empty' cylinders have the valve closed to prevent evaporation of acetone.

Close cylinder valve before shutting off regulator, to permit gas to bleed from regulator.

When used e.g. for welding, avoid the careless use of flame which could fuse the metal safety plug in the cylinder.

In the event of fire issuing from the cylinder, close the gas supply if it is safe to do so and evacuate the area.

Consider the need for detection/alarm systems and in any event check periodically for leaks with e.g. soap solution, *never* with a naked flame.

## Air

The physical properties of air are given in Table 9.5. Air is a mixture of nitrogen, oxygen, argon,

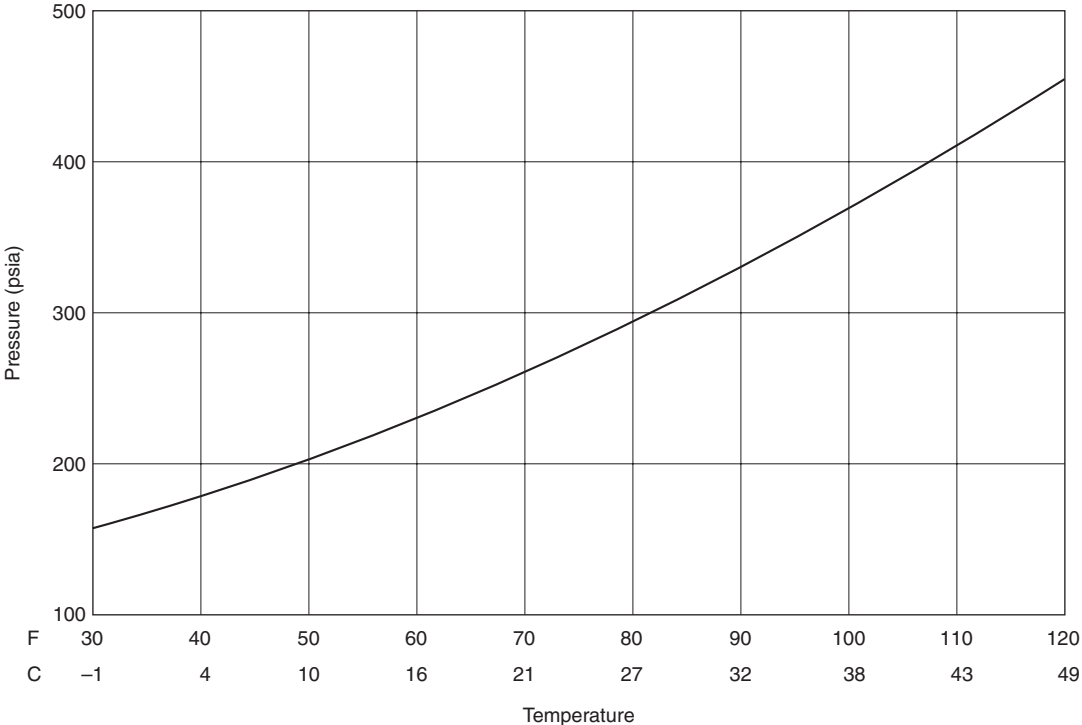


Figure 9.1 Acetylene (in acetone): full cylinder pressure versus temperature

carbon dioxide, water vapour, rare gases and trace quantities of ozone, oxides of nitrogen, acetylene, methane and other hydrocarbons. Its composition varies with altitude. Dry air is inert in its effect on metals and plastics. The hazards associated with compressed air, in addition to those associated with any pressure system (i.e. the potential for rupture of equipment or pipework), are:

- From inhalation at pressures above atmospheric, used in tunnelling or diving, or from breathing apparatus or resuscitation equipment, if the pressure is too high or exposure is prolonged. This may cause symptoms from pain to dyspnoea, disorientation and unconsciousness; it may be fatal.
- From particulate matter blown from orifices or surfaces, e.g. into the eyes.
- From entry into any of the body orifices, which can result in serious internal damage.
- From penetration of unbroken skin, or cuts. Foreign matter, e.g. grease, metal, concrete, may also be injected into subcutaneous tissues.
- From whipping of an unsecured hose on rapid gas release.

Table 9.5 Physical properties of air

|                        |                                                          |
|------------------------|----------------------------------------------------------|
| Density @ 20 C, 1 atm  | 0.0012046 g/l                                            |
| Critical temperature   | -140.6 C                                                 |
| Critical pressure      | 546.8 psia (37.2 atm) (38.4 kg/cm <sup>2</sup> absolute) |
| Critical density       | 0.313 g/ml                                               |
| Viscosity @ 0 C, 1 atm | 170.9 micropoises                                        |

The precautions include:

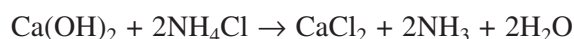
Prohibition on playing around with compressed air hoses, e.g. aiming directly at any individual. Avoidance of blowing away dust or dirt from equipment, the floors, or clothing etc. (which may also produce a dust inhalation or explosion hazard).

Direction of the exhaust air from tools away from the operator.

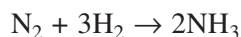
Proper training and instruction for anyone required to use air-fed breathing apparatus. Restriction of exposures to compressed air to safe levels.

## Ammonia

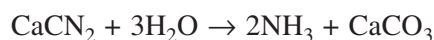
Ammonia can be made on a small scale by heating an intimate mixture of ammonium chloride and dry slaked lime in a ratio of 1:3, respectively:



Industrially, production is either from the Haber process at high pressure:



or the cyanamide process



At room temperature and atmospheric pressure ammonia is a colourless, alkaline gas with a pungent smell. It dissolves readily in water. Physical properties are summarized in Table 9.6. The effect of temperature on vapour pressure of anhydrous ammonia is shown in Figure 9.2.

Ammonia is shipped as a liquefied gas under its own vapour pressure of 114 psig (7.9 bar) at 21 °C. Uses are to be found in refrigeration, fertilizer production, metal industries, the petroleum, chemical and rubber industries, domestic cleaning agents and water purification. Aqueous solutions of ammonia are common alkaline laboratory reagents; ca 0.88 solution is the strongest available. Ammonia gas is expelled on warming.

Ammonia gas is irritating to the eyes, mucous membranes and respiratory tract. Because of its odour few individuals are likely to be unwittingly over-exposed for prolonged periods. Table 9.7 summarizes the physiological effects of human exposure. Clearly at high concentrations the gas becomes corrosive and capable of causing extensive injuries. Thus 1% in air is mildly irritating, 2% has a more pronounced effect and 3% produces stinging sensations.

On contact with the skin, liquid ammonia produces severe burns compounded by frostbite due to the freezing effect from rapid evaporation from the skin.

Moist ammonia attacks copper, tin, zinc and their alloys. Ammonia is also flammable with flammability limits of 15–28%.

Ammonia can also react violently with a large selection of chemicals including ethylene oxide, halogens, heavy metals, and oxidants such as chromium trioxide, dichlorine oxide, dinitrogen tetroxide, hydrogen peroxide, nitric acid, liquid oxygen, and potassium chlorate.

Besides the control measures given in Table 9.3, the following precautions are appropriate:

Wear rubber gloves, chemical goggles and, depending upon scale, a rubber apron or full chemical suit.

Never heat ammonia cylinders directly with steam or flames to speed up gas discharge.

**Table 9.6 Physical properties of ammonia**

|                                                |                                                   |
|------------------------------------------------|---------------------------------------------------|
| Molecular weight                               | 17.031                                            |
| Vapour pressure at 21 °C (cylinder pressure)   | 7.87 bar                                          |
| Specific volume at 21 °C, 1 atm                | 1.411 ml/g                                        |
| Boiling point at 1 atm                         | – 33.35 °C                                        |
| Triple point at 1 atm                          | – 77.7 °C                                         |
| Triple point pressure                          | 1.33 mbar                                         |
| Specific gravity, gas at 0 °C, 1 atm (air = 1) | 0.5970                                            |
| Density, gas at boiling point                  | 0.000 89 g/ml                                     |
| Density, liquid at boiling point               | 0.674 g/ml                                        |
| Critical temperature                           | 132.44 °C                                         |
| Critical pressure                              | 113 bar                                           |
| Critical density                               | 0.235 g/ml                                        |
| Flammable limits in air                        | 15–28% by volume                                  |
| Latent heat of vaporization at boiling point   | 327.4 cal/g                                       |
| Specific heat, liquid at –20 °C                | 1.126 cal/g °C                                    |
| Specific heat, gas at 25 °C, 1 atm             |                                                   |
| $C_p$                                          | 0.5160 cal/g °C                                   |
| $C_v$                                          | 0.4065 cal/g °C                                   |
| ratio, $C_p/C_v$                               | 1.269                                             |
| Thermal conductivity, gas at 25 °C, 1 atm      | $5.22 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Entropy, gas at 25 °C, 1 atm                   | 2.7 cal/g °C                                      |
| Heat of formation, gas at 25 °C                | –648.3 cal/g                                      |
| Solubility at 0 °C, 1 atm                      |                                                   |
| in water                                       | 42.8% by weight                                   |
| in methanol, absolute                          | 29.3% by weight                                   |
| in ethanol, absolute                           | 20.95% by weight                                  |
| Viscosity, gas at 0 °C, 1 atm                  | 0.009 18 cP                                       |
| Viscosity, liquid at –33.5 °C                  | 0.266 cP                                          |

Use under well-ventilated conditions and provide convenient safety showers and eye-wash facilities.

Ensure that gas cannot be accidentally ignited.

Check for leaks, e.g. with moist litmus paper or concentrated hydrochloric acid (which forms dense white fumes of ammonium chloride).

In the event of accident, administer first aid (see Table 9.9).

## Carbon dioxide

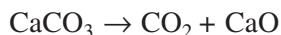
Carbon dioxide is present in air and is a constituent of natural gas escaping from mineral springs and fissures in the earth's surface. It is also the ultimate product of combustion of carbon and its compounds. Laboratory scale preparation usually entails reaction between dilute hydrochloric acid and marble (calcium carbonate):



Industrially, it is obtained as a by-product of fermentation of sugar to alcohol:



or by burning coke/limestone mixture in a kiln:



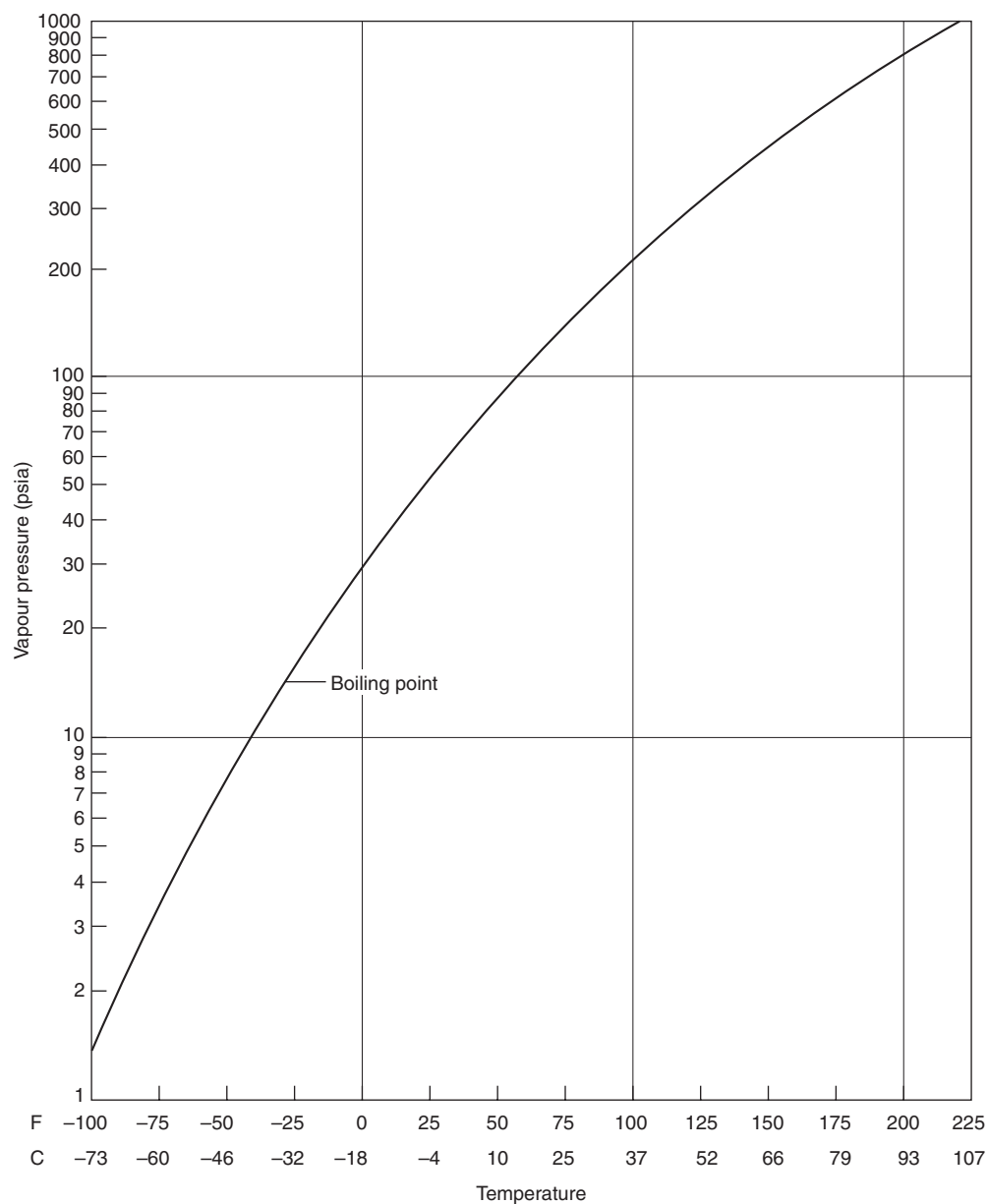


**Figure 9.2** Ammonia vapour pressure versus temperature

Liquid carbon dioxide is discussed on page 261. Carbon dioxide gas is commonly used for carbonating drinks, in fire extinguishers, for gas-shielding of welding and in shell moulding in foundries. Its physical and toxicological properties are summarized in Tables 8.5, 8.6 and 5.29.

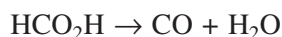
The gas is non-flammable, and is used for inert gas purging. Because it is 1.5 times heavier than air it may accumulate at low level. The general handling precautions are those in Table 9.3.

**Table 9.7 Physiological effects of ammonia**

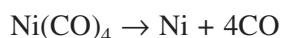
| <i>Atmospheric concentration<br/>(ppm)</i> | <i>Effects</i>                                                               |
|--------------------------------------------|------------------------------------------------------------------------------|
| 20                                         | First perceptible odour                                                      |
| 40                                         | A few individuals may suffer slight eye irritation                           |
| 100                                        | Noticeable irritation of eyes and nasal passages after few minutes' exposure |
| 400                                        | Severe irritation of the throat, nasal passages and upper respiratory tract  |
| 700                                        | Severe eye irritation                                                        |
|                                            | No permanent effect if exposure <30 min                                      |
| 1700                                       | Serious coughing, bronchial spasms, <30 min exposure may be fatal            |
| 5000                                       | Serious oedema, strangulation, asphyxia                                      |
|                                            | Fatal almost immediately                                                     |

## Carbon monoxide

Carbon monoxide is produced by incomplete combustion of carbon and its compounds. In the laboratory it can be prepared by careful dehydration of formic or oxalic acid with sulphuric acid:



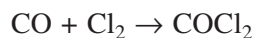
Traditionally, pure CO is not used industrially; water gas or producer gas are used instead. However, pure CO is made by thermal decomposition of nickel carbonyl:



Carbon monoxide is a toxic, flammable, colourless and odourless gas which is slightly lighter than air and slightly soluble in water. Some physical constants are given in Table 9.8. Corrosion by pure carbon monoxide is considered negligible. It is shipped as a non-liquefied gas in high-pressure steel containers. Its main uses include fuel gas mixtures with hydrogen and for reduction of ores. Its main hazards are its extreme toxic effects which stem from its ability to complex with haemoglobin (with which it has an affinity 300 times that of oxygen) resulting in chemical asphyxiation (see Table 5.31). It burns in air with a characteristic blue flame. It combines directly with chlorine in sunlight to produce highly toxic phosgene:

**Table 9.8 Physical properties of carbon monoxide**

|                                    |                            |
|------------------------------------|----------------------------|
| Molecular weight                   | 28.01                      |
| Specific volume @ 21 °C, 1 atm     | 13.8 cu.ft/lb (861.5 ml/g) |
| Boiling point @ 1 atm              | -191.5 °C                  |
| Triple point                       | -205.01 °C                 |
| Specific gravity @ 21 °C, 1 atm    | 115.14 mm Hg               |
| Density (liquid) @ bp              | 0.9678                     |
| Latent heat of vaporization @ bp   | 1444 cal/mole              |
| Latent heat of fusion @ tp         | 200.9 cal/mole             |
| Flammable limits in air            | 12.5–74%                   |
| Autoignition temperature           | 650 °C                     |
| Specific heat (gas) @ 25 °C, 1 atm |                            |
| $C_p$                              | 0.2491 cal/g °C            |
| $C_v$                              | 0.1774 cal/g °C            |
| ratio $C_p/C_v$                    | 1.4                        |
| Viscosity (gas) @ 0 °C, 1 atm      | 0.0166 centipoise          |
| Entropy (gas) @ 25 °C              | 47.266 cal/mole °C         |
| Heat of formation (gas) @ 25 °C    | -26.417 kcal/mole          |



Liquid carbon monoxide in the presence of nitrous oxide poses blast hazards.

Precautions for handling carbon monoxide in compressed gas cylinders in addition to those given in Table 9.3 include:

- Handle in well-ventilated conditions.
- Consider the need for respiratory equipment.
- Use CO gas detection system if used indoors or in confined spaces.
- Check the system periodically for leaks.
- Avoid accidental contact with ignition sources.
- Segregate stocks from oxygen cylinders or other oxidizing or flammable substances.

**Table 9.9 First aid measures following exposure to a compressed gas**

|                                        |                                                                                                                                                                                                                                                                                                              |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Obtain medical help immediately</b> |                                                                                                                                                                                                                                                                                                              |
| <b>Inhalation</b>                      | Remove victim to uncontaminated area and carry out artificial respiration<br>In the case of hydrogen sulphide, ensure that the patient remains rested and refrains from exercise for 24 hr<br>For chlorine gassing, lay victim on stomach with head and shoulders slightly lowered; discourage from coughing |
| <b>Skin contact</b>                    | Use emergency shower, removing contaminated clothing and shoes at the same time                                                                                                                                                                                                                              |
| <b>Eye contact</b>                     | Wash promptly with copious amounts of water for $\geq 15$ min                                                                                                                                                                                                                                                |

## Chlorine

Chlorine can be made on a small scale by oxidation of hydrogen chloride with, e.g., manganese dioxide:



Industrially, chlorine is obtained as a by-product in the electrolytic conversion of salt to sodium hydroxide. Hazardous reactions have occurred between chlorine and a variety of chemicals including acetylene, alcohols, aluminium, ammonia, benzene, carbon disulphide, diethyl ether, diethyl zinc, fluorine, hydrocarbons, hydrogen, ferric chloride, metal hydrides, non-metals such as boron and phosphorus, rubber, and steel.

Chlorine is very reactive and finds wide use, e.g. in water purification, sanitation, as a bleaching agent, as a versatile raw material in synthetic chemistry etc. In liquid form, chlorine is a clear amber dense liquid. The gas is greenish-yellow, about 2.5 times as dense as air. Although non-flammable, it will support combustion. Liquid chlorine causes severe irritation and blistering of skin. The gas has a pungent suffocating odour and is irritant to the nose and throat. It is an extremely powerful blistering agent and respiratory irritant. Persons exposed to chlorine become restless, sneeze, develop sore throat and salivate copiously. Effects on the body are summarized in Table 9.10 and physical characteristics are given in Table 9.11.

Moist chlorine is corrosive to skin and to most common materials of construction. Wet chlorine at low pressure can be handled in chemical stoneware, glass or porcelain and in certain alloys and plastics.

The effect of temperature on vapour pressure is shown in Figure 9.3. Cylinders are normally protected from over-pressurization by a fusible metal plug melting at about 85 °C.

**Table 9.10 Physiological effects of chlorine**

| <i>Atmospheric concentration (ppm)</i> | <i>Effects</i>                                                     |
|----------------------------------------|--------------------------------------------------------------------|
| 1                                      | Minimum concentration causing slight symptoms after several hours  |
| 3.5                                    | Minimum concentration detectable by odour                          |
| 4                                      | Maximum concentration that can be breathed for 1 hr without damage |
| 15                                     | Minimum concentration causing throat irritation                    |
| 30                                     | Minimum concentration causing coughing                             |
| 40–60                                  | Concentration dangerous within 30 min                              |
| 1000                                   | Concentration likely to be fatal after a few deep breaths          |

**Table 9.11 Physical properties of chlorine**

|                                                |                                                  |
|------------------------------------------------|--------------------------------------------------|
| Molecular weight                               | 70.906                                           |
| Vapour pressure at 21 °C                       | 5.88 bar                                         |
| Specific volume at 21 °C, 1 atm                | 337.1 ml/g                                       |
| Boiling point at 1 atm                         | –34.05 °C                                        |
| Freezing point at 1 atm                        | –100.98 °C                                       |
| Specific gravity, gas at 0 °C, 1 atm (air = 1) | 2.49                                             |
| Specific gravity, liquid at 20 °C              | 1.41                                             |
| Density, gas at 0 °C, 1 atm                    | 3.214 g/l                                        |
| Density, liquid at 0 °C, 3.65 atm              | 1.468 g/l                                        |
| Critical temperature                           | 144 °C                                           |
| Critical pressure                              | 77.1 bar                                         |
| Critical density                               | 0.573 g/ml                                       |
| Latent heat of vaporization at boiling point   | 68.8 cal/g                                       |
| Heat of fusion at flash point                  | 22.9 cal/g                                       |
| Specific heat, liquid at 0–24 °C               | 0.226 cal/g °C                                   |
| Specific heat, gas at 15 °C, 1 atm             |                                                  |
| $C_p$                                          | 0.115 cal/g °C                                   |
| $C_v$                                          | 0.085 cal/g °C                                   |
| ratio $C_p/C_v$                                | 1.355                                            |
| Thermal conductivity, gas at 0 °C              | $1.8 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Viscosity, gas at 20 °C, 1 atm                 | 0.0147 cP                                        |
| Viscosity, liquid at 20 °C                     | 0.325 cP                                         |
| Solubility in water at 20 °C, 1 atm            | 7.30 g/l                                         |

The following safety measures supplement the general precautions listed in Table 9.3:

Provide convenient showers, eye-wash facilities and appropriate respiratory protection for emergencies.

Work in well-ventilated area wearing appropriate skin protection and respiratory equipment.

Check for leaks (e.g. with aqueous ammonia) and consider the need for detection/alarm systems.

Leaks should be dealt with immediately after evacuating the area.

Never connect the cylinder directly to vessels of liquid since suck-back into the cylinder may result in violent reaction. Insert a trap in the line between the chlorine supply and the receiver of sufficient capacity to accommodate all the liquid.

Never supply heat directly to the cylinder.

Segregate stocks of chlorine from acetylene, hydrogen, ammonia and fuel gases and ensure no accidental contact with ethers, hydrocarbons and other organics and finely divided metals.

Never mix chlorine with another gas in the cylinder.

In the event of exposure, apply first aid as in Table 9.9 (refer also to Table 13.17).



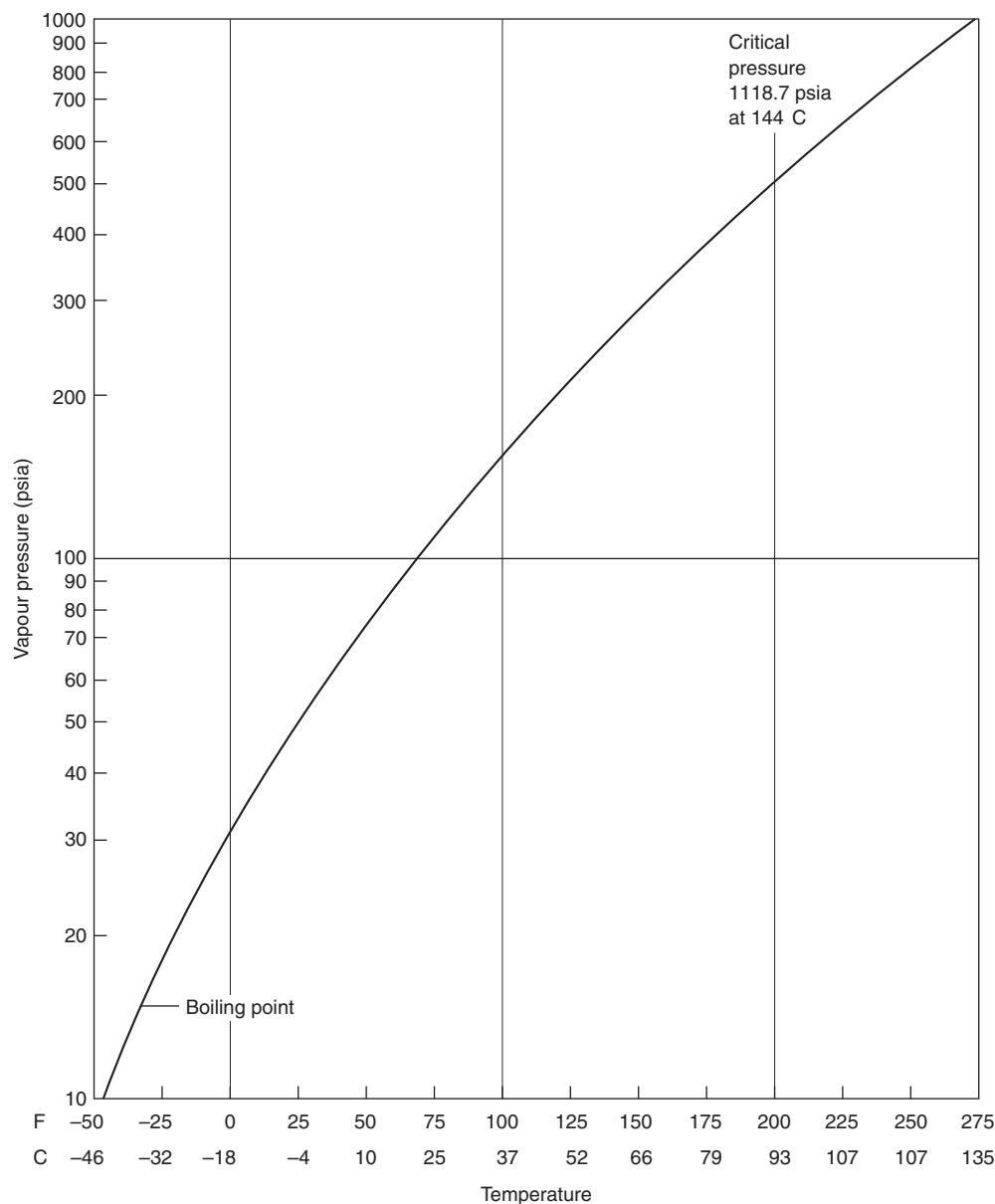
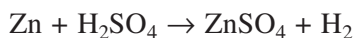


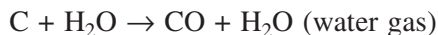
Figure 9.3 Chlorine vapour pressure versus temperature

## Hydrogen

Hydrogen does not appear free in the atmosphere except at levels below 1 ppm, since rapid diffusivity enables molecules to escape the earth's gravitational field and it is continuously lost from the atmosphere. It is present in the earth's crust at about 0.87% in combination with oxygen in water and with carbon and other elements in organic substances. It is prepared commercially on a small scale by action of sulphuric acid on zinc:



and industrially by electrolysis of sodium chloride, or sodium hydroxide, or by reduction of steam by carbon monoxide:



Hydrogen is used for the hydrogenation of oils and fats, in metallurgy, metal welding/cutting, ammonia synthesis and petroleum refining. It is the lightest gas known. It is colourless and odourless, only slightly soluble in water but readily soluble in hydrocarbons. Hydrogen is non-toxic but can act as an asphyxiant. It is usually shipped in containers at 2000 psig (137.9 bar) at 21 C, often protected by frangible discs backed up by a fusible metal plug melting at 100 C. Physical properties are given in Table 9.12.

**Table 9.12 Physical properties of hydrogen**

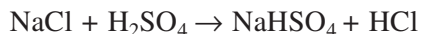
|                                                  |                                    |
|--------------------------------------------------|------------------------------------|
| Molecular weight                                 | 2.016                              |
| Specific volume at 21 C, 1 atm                   | 11 967 ml/g                        |
| Boiling point at 1 atm                           | -252.9 C                           |
| Triple point at 0.0695 atm                       | -259.3 C                           |
| Specific gravity, gas at 23.9 C, 1 atm (air = 1) | 0.06952                            |
| Density, gas at 0 C, 1 atm                       | 0.0899 g/l                         |
| Density, liquid at -253 C, 1 atm                 | 0.0708 g/ml                        |
| Critical temperature                             | -240.2 C                           |
| Critical pressure                                | 12.98 bar                          |
| Critical density                                 | 0.03136 g/ml                       |
| Latent heat of vaporization at boiling point     | 106.5 cal/g                        |
| Latent heat of fusion at triple point            | 13.875 cal/g                       |
| Flammable limits in air                          | 4.0–75% by volume                  |
| Auto-ignition temperature                        | 585 C                              |
| Specific heat, gas at 0–200 C, 1 atm             |                                    |
| $C_p$                                            | 3.44 cal/g C                       |
| $C_v$                                            | 2.46 cal/g C                       |
| ratio $C_p/C_v$                                  | 1.40                               |
| Thermal conductivity at 0 C                      | 0.00040 cal/s cm <sup>2</sup> C/cm |
| Viscosity, gas at 15 C, 1 atm                    | 0.0087 cP                          |
| Solubility in water at 15.6 C, 1 atm             | 0.019 vol/vol H <sub>2</sub> O     |

The main danger with hydrogen is of fire or explosion. Hydrogen burns in chlorine to yield hydrogen chloride. Although relatively inactive at ambient temperature it reacts with many elements either at high temperatures or in the presence of catalysts and can react dangerously with air, acetylene, aromatics, unsaturated organic matter, halogens, metals such as lithium, calcium, barium, strontium and potassium, and with oxidants such as chlorine dioxide, oxides of nitrogen and palladium oxides. The following precautions are important to supplement those in Table 9.3:

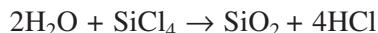
- Use only in well-ventilated conditions to avoid accumulation at high levels.
- Eliminate means of accidental ignition.
- Use only explosion-proof electrical equipment and spark-proof tools.
- Ground all equipment and lines used with hydrogen.
- Check for leaks with soapy water and consider the need for automatic detection/alarms.

## Hydrogen chloride

Hydrogen chloride may be conveniently prepared by heating sodium chloride with sulphuric acid:



When this reaction has occurred accidentally sufficient hydrogen chloride has been liberated to explosively burst the vessel. The purest form of hydrogen chloride is made by the action of water on silicon tetrachloride:



Commercially, hydrogen chloride is obtained either as a by-product in the manufacture of salt cake from sodium chloride, or by allowing chlorine produced as a by-product in electrolytic processes to react with hydrogen in the presence of activated charcoal. It is also formed as a by-product in the manufacture of phenol.

Anhydrous hydrogen chloride is a colourless, pungent, heavy, corrosive, thermally-stable gas with a suffocating odour. It is heavier than air and fumes strongly in moist air and is highly soluble in water with evolution of much heat. Physical properties are given in Table 9.13 and its pressure vs temperature profile in Figure 9.4. It is shipped as a liquefied gas with a cylinder pressure of about 613 psig at 21 °C and platinum coated frangible bursting discs and fusible metal plugs. Its main uses are as a chemical intermediate and in hydrochlorinations. Its toxicity results from its severe irritating effects to the upper respiratory tract and corrosivity towards skin, eyes and mucous membranes. Neutralization of alkalis in tissues can result in death from oedema or spasm of the larynx. At exposures of 50–100 ppm work is impossible, and difficult at 10–50 ppm; the TLV is a short-term exposure limit of 5 ppm ceiling.

**Table 9.13 Physical properties of hydrogen chloride**

|                                      |                      |
|--------------------------------------|----------------------|
| Molecular weight                     | 36.46                |
| Vapour pressure @ 21 °C              | 613 psig             |
| Specific volume @ 21 °C, 1 atm       | 661.7 ml/g           |
| Boiling point @ 1 atm                | –85.03 °C            |
| Freezing point @ 1 atm               | –114.19 °C           |
| Specific gravity (gas) @ 0 °C, 1 atm | 1.268                |
| Density (gas) @ 0 °C, 1 atm          | 1.639 g/l            |
| Density (liquid) @ –36 °C            | 1.194 g/l            |
| Critical temperature                 | 51.4 °C              |
| Critical pressure                    | 1198 psia (81.5 atm) |
| Critical density                     | 0.42 g/ml            |
| Latent heat of vaporization @ bp     | 103.12 cal/g         |
| Specific heat (gas) @ 15 °C, 1 atm   |                      |
| $C_p$                                | 0.1939 cal/g °C      |
| $C_v$                                | 0.1375 cal/g °C      |
| ratio $C_p/C_v$                      | 1.41                 |
| Viscosity (gas) @ 20 °C, 1 atm       | 0.0156 cP            |
| Solubility in water @ 0 °C, 1 atm    | 82.31 g/100 g water  |

The gas is essentially inert to common materials of construction such as stainless steel under normal conditions of use. Platinum and gold are also not attacked by pure hydrogen chloride.

In the presence of moisture, however, most metals are corroded and it is advised that the proposed use and pressures are discussed with the supplier so that suitable construction materials are established prior to installation. Hydrogen chloride neither burns nor supports combustion,

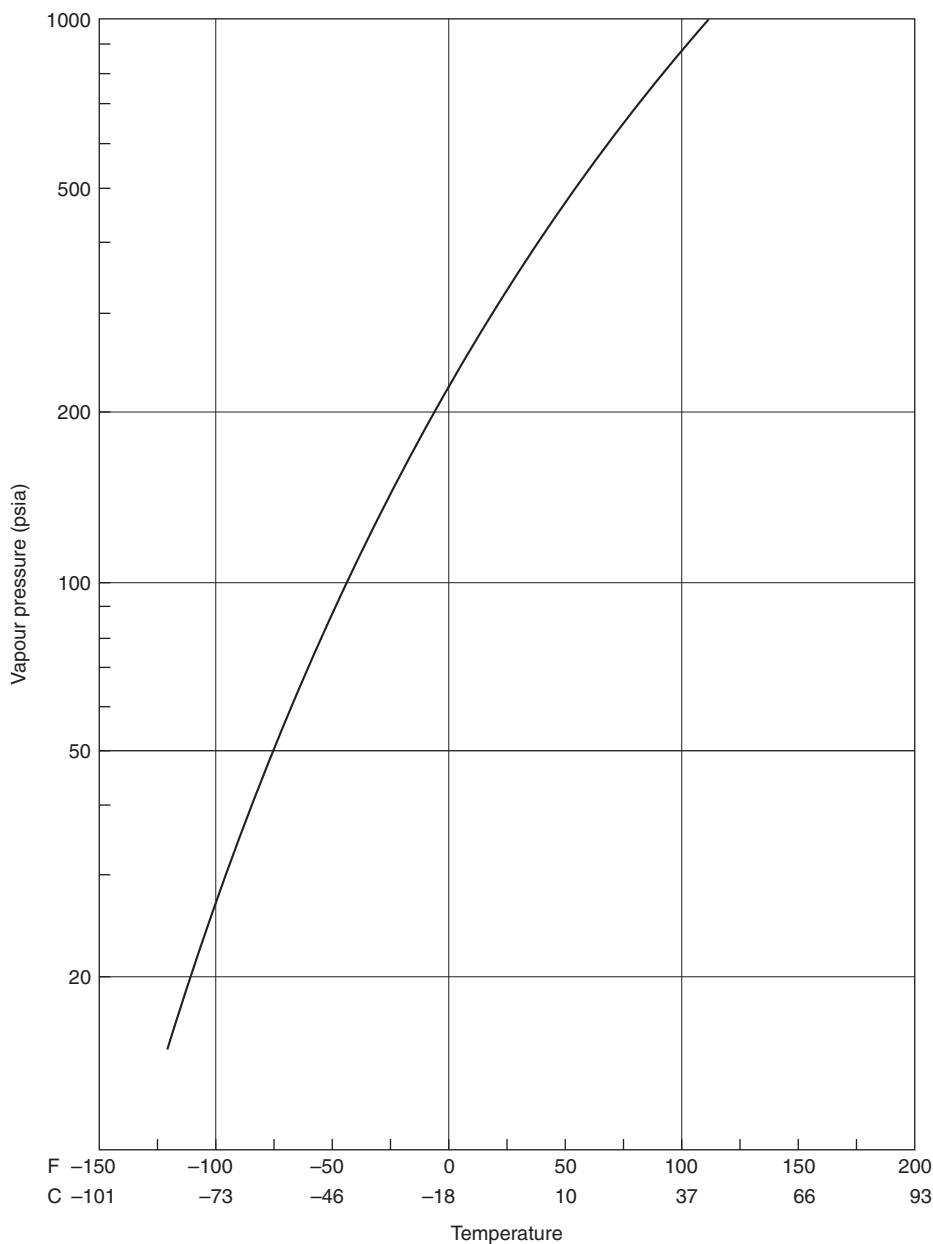


**Figure 9.4** *Hydrogen chloride vapour pressure vs temperature*

although burning sodium will continue to burn in it forming hydrogen and sodium chloride. Hydrogen chloride gas has produced runaway reactions with dinitrotoluene, fluorine (with ignition), sodium, and alcoholic hydrogen cyanide.

Liquid hydrogen chloride does not conduct electricity and is without action on zinc, iron, magnesium, calcium oxide and certain carbonates. However, it does dissolve aluminium.

Some special precautions for use of compressed hydrogen chloride gas include:

Store and use under ventilated conditions.

Avoid galvanized pipe and brass or bronze fittings.

Wear protective clothing such as rubber or plastic aprons, rubber gloves, gas-tight goggles and respiratory equipment as appropriate.

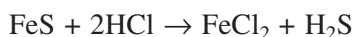
Ensure fast-acting showers are available close to site of use/storage plus eye-wash fountains or similar facilities for eye irrigation.

Prevent suck-back of foreign material into the cylinder by use of check valves or vacuum break traps.

Switch off gas lines from use backwards to the cylinder.

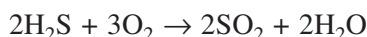
## Hydrogen sulphide

Hydrogen sulphide is usually prepared on a small scale by the action of hydrochloric acid on ferrous sulphide:

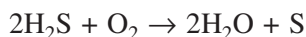


The purest form is obtained by passing a mixture of sulphur vapour and hydrogen over finely divided nickel at 450 °C.

Hydrogen sulphide is used in the preparation of metal sulphides, oil additives etc., in the purification and separation of metals, as an analytical reagent and as raw material in organic synthesis. It burns in air with a blue flame:



or if oxygen is depleted:



Hydrogen sulphide occurs naturally, e.g. in natural gas and petroleum, volcanic gases, and from decaying organic matter. It may be present near oil wells and where petroleum is processed. Commercially it is obtained as a by-product from many chemical reactions including off-gas in the production of some synthetic polymers (e.g. rayon, nylon) from petroleum products, and by the action of dilute mineral acids on metal sulphides. Physical properties are summarized in Table 9.14 and effects of temperature on vapour pressure are shown in Figure 9.5.

Hydrogen sulphide is a dense, colourless, highly flammable water-soluble gas with an offensive odour of rotten eggs. It is highly toxic; its effects on the body are given in Table 5.32. Acute poisoning may result from exposures at or above 700 ppm due to systemic effects, including attack on the nervous system and respiratory collapse. Hydrogen sulphide may become rapidly oxidized on contact with a range of metal oxides and in certain cases may ignite or explode. It can also react dangerously with a host of oxidants, rust and soda lime.

Cylinders are typically protected from over-pressurization by frangible gold-plated discs and fusible plugs.

Important precautions include:

Use in well-ventilated conditions and eliminate sources of ignition.

Operators should work in pairs.

Do not rely on the sense of smell to detect hydrogen sulphide leaks. Strips of wet lead acetate paper turn black on exposure to hydrogen sulphide and offer a simple indicator, as do colour indicator tubes. For plant-scale operations, instrumental multi-point detectors and alarms are likely to be more appropriate.

**Table 9.14 Physical properties of hydrogen sulphide**

|                                                 |                                                   |
|-------------------------------------------------|---------------------------------------------------|
| Molecular weight                                | 34.08                                             |
| Vapour pressure at 21 °C                        | 17.4 bar                                          |
| Specific volume at 21 °C, 1 atm                 | 701 ml/g                                          |
| Boiling point at 1 atm                          | -60.33 °C                                         |
| Freezing point at 1 atm                         | -85.49 °C                                         |
| Specific gravity, gas at 15 °C, 1 atm (air = 1) | 1.1895                                            |
| Density, gas at 0 °C, 1 atm                     | 1.5392 g/l                                        |
| Density, liquid at boiling point                | 0.993 g/ml                                        |
| Critical temperature                            | 100.4 °C                                          |
| Critical pressure                               | 90.23 bar                                         |
| Critical density                                | 0.349 g/ml                                        |
| Latent heat of vaporization at boiling point    | 131 cal/g                                         |
| Latent heat of fusion at melting point          | 16.7 cal/g                                        |
| Specific heat, gas at 25 °C, 1 atm              |                                                   |
| $C_p$                                           | 0.240 cal/g °C                                    |
| $C_v$                                           | 0.181 cal/g °C                                    |
| ratio $C_p/C_v$                                 | 1.32                                              |
| Thermal conductivity at 0 °C                    | $3.05 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Flammable limits in air                         | 4.3–45% by volume                                 |
| Auto-ignition temperature                       | 260 °C                                            |
| Solubility in water at 20 °C, 1 atm             | 0.672 g/100 ml water                              |
| Viscosity, gas at 0 °C, 1 atm                   | 0.01166 cP                                        |

Segregate cylinders of hydrogen sulphide from oxygen or other highly-oxidizing or combustible materials.

Ground all lines and equipment used with hydrogen sulphide.

Insert traps in the line to prevent suck-back of liquid into the cylinder.

Provide respiratory protection for emergencies.

In the event of exposure, apply first aid as indicated in Table 9.9.

## Liquefied petroleum gases (LPG)

LPG is a mixture of propane and *n*- and iso-butanes, plus small amounts of their olefinic counterparts. The main sources are natural gas wells, gas from crude oil wells and the cracking of crude oil. The requirements for commercial LPG are defined in national standards and a stenching agent is added for some uses.

The common LPGs in general use are commercial propane, comprising predominantly propane and/or propylene, and commercial butane. The physico-chemical properties of propane and the butanes are given in Table 9.15. These compounds are gaseous at normal ambient temperature and pressure but are readily liquefied by the application of moderate pressure. They are stored and distributed as liquids in low pressure cylinders or bulk containers at ambient temperature and allowed to revert to gas at the point of use. Large-scale storage and shipment by sea is in refrigerated vessels at close to atmospheric pressure.

Butane itself is considered to be insoluble in water. Exposures of up to 5% for 2 hours appear not to present problems. The TLV is 800 ppm. The relationship between pressure and temperature is given by Figure 9.6.

Propane has a characteristic natural gas odour and is basically insoluble in water. It is a simple asphyxiant but at high concentrations has an anaesthetic effect. The TLV is 2500 ppm. It is usually shipped in low-pressure cylinders as liquefied gas under its own vapour pressure of ca 109 psig at 21 °C. Its pressure/temperature profile is given in Figure 9.7.

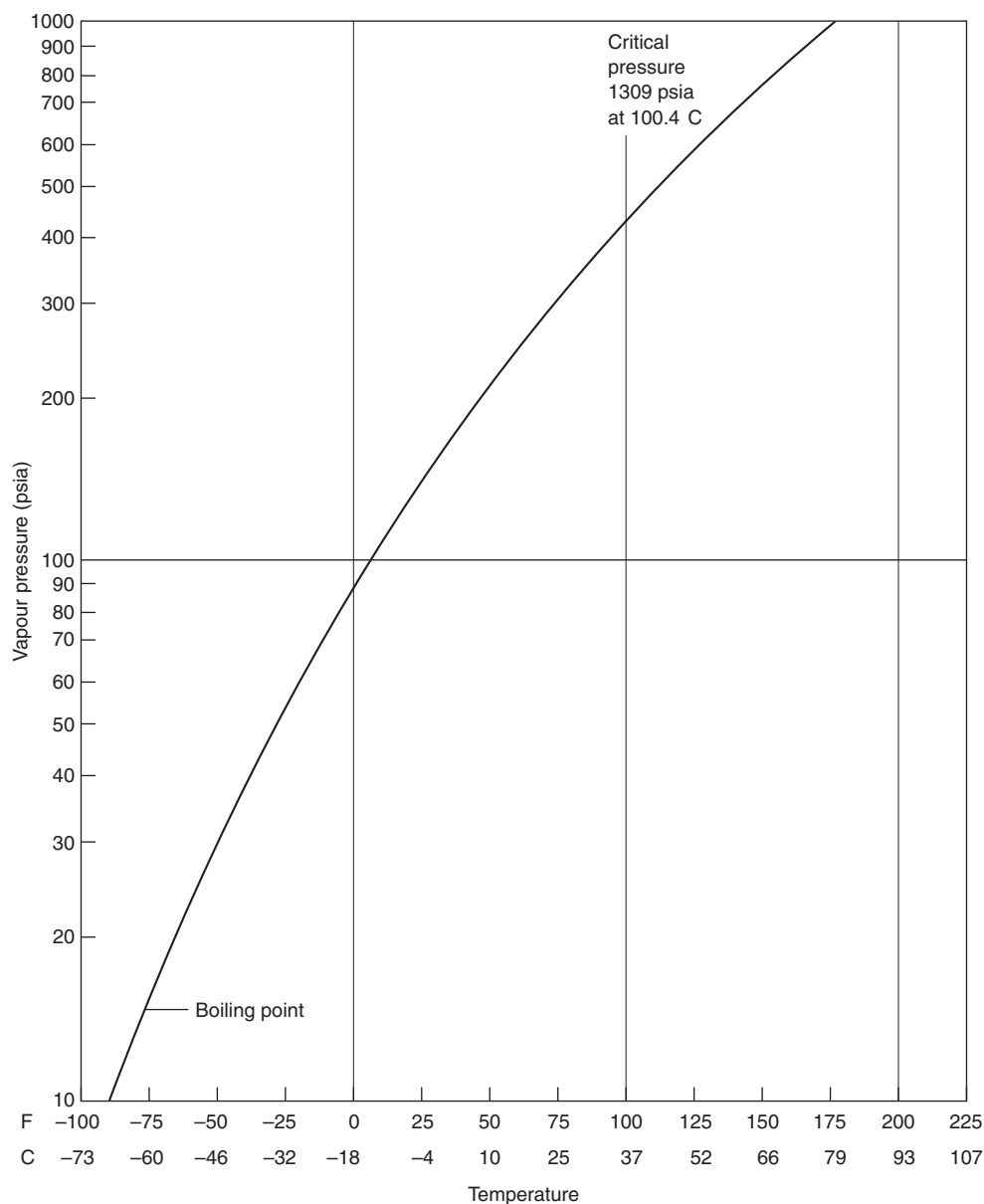


Figure 9.5 Hydrogen sulphide vapour pressure vs temperature

LPG is considered to be non-toxic with no chronic effects, but the vapour is slightly anaesthetic. In sufficiently high concentrations, resulting in oxygen deficiency, it will result in physical asphyxiation. The gases are colourless and odourless but an odorant or stenching agent (e.g. methyl mercaptan or dimethyl sulphide) is normally added to facilitate detection by smell down to approximately 0.4% by volume in air, i.e. one-fifth of the lower flammable limit. The odorant is not added for specific applications, e.g. cosmetic aerosol propellant.

The main danger with LPG arises from its flammability. Fire or explosion may be fuelled by gas escape from leaking cylinders, from an appliance which has not been turned off properly, or

Table 9.15 Properties of LPGs

|                                                                                                                       | <i>Propane</i> | <i>Butane</i> | <i>isoButane</i> |
|-----------------------------------------------------------------------------------------------------------------------|----------------|---------------|------------------|
| Molecular weight                                                                                                      | 44.1           | 58.1          | 58.1             |
| Vapour pressure at 21 °C, i.e. cylinder pressure (kg/cm <sup>2</sup> gauge)                                           | 7.7            | 1.15          | 21.6             |
| Specific volume at 21 °C/l atm (ml/g)                                                                                 | 530.6          | 399.5         | 405.8            |
| Bp at 1 atm (°C)                                                                                                      | −42.07         | −0.5          | −11.73           |
| Mp at 1 atm (°C)                                                                                                      | −187.69        | −138.3        | −159.6           |
| SG, gas at 16 °C/l atm (air = 1)                                                                                      | 1.5503         | 2.076         | 2.01             |
| Density, liquid at sat. pressure (g/ml)                                                                               | 0.5505         | 0.5788        | 0.563            |
|                                                                                                                       | (20 °C)        | (20 °C)       | (15 °C)          |
| Density, gas at 0 °C/l atm (kg/m <sup>3</sup> )                                                                       | 2.02           | 2.70          | —                |
| Critical temperature (°C)                                                                                             | 96.8           | 152           | 135              |
| Critical pressure (atm)                                                                                               | 42             | 37.5          | 37.2             |
| Critical density (g/ml)                                                                                               | 0.220          | 0.225         | 0.221            |
| Latent heat of vap. at bp (cal/g)                                                                                     | 101.76         | 92.0          | 87.56            |
| Latent heat of fusion at mp (cal/g)                                                                                   | 19.10          | 19.17         | 18.67            |
| Specific heat, liquid at 16 °C (cal/g °C)                                                                             | —              | 0.5636        | 0.5695           |
| Specific heat, gas at 16 °C:                                                                                          |                |               |                  |
| C <sub>p</sub> (cal/g °C)                                                                                             | 0.3885         | 0.3908        | 0.3872           |
| C <sub>v</sub> (cal/g °C)                                                                                             | 0.3434         | 0.3566        | 0.3530           |
| ratio C <sub>p</sub> /C <sub>v</sub>                                                                                  | 1.13           | 1.1           | 1.1              |
| Specific heat ratio at 16 °C/l atm, C <sub>p</sub> /C <sub>v</sub>                                                    | 1.131          | 1.096         | 1.097            |
| Gross heat of combustion at 16 °C/l atm (cal/ml)                                                                      | 22.8           | 30.0          | 29.8             |
| Viscosity, gas at 1 atm (centipoise)                                                                                  | 0.00803        | 0.0084        | 0.00755          |
|                                                                                                                       | (16 °C)        | (15 °C)       | (23 °C)          |
| Coefficient of cubical expansion at 15 °C (per °C)                                                                    | 0.0016         | 0.0011        | —                |
| Surface tension (dynes/cm)                                                                                            | 16.49          | 16.02         | 15.28            |
|                                                                                                                       | (−50 °C)       | (−10 °C)      | (−20 °C)         |
| Solubility in water at 1 atm (volumes/100 volumes water)                                                              | 6.5            | —             | 1.7              |
|                                                                                                                       | (18 °C)        | —             | (17 °C)          |
| Flammable limits in air (% by volume)                                                                                 | 2.2–9.5        | 1.9–8.5       | 1.8–8.4          |
| Autoignition temp. (°C)                                                                                               | 467.8          | 405           | 543              |
| Max. explosion pressure (MPa)                                                                                         | 0.86           | 0.86          | —                |
| Min. ignition energy (MJ)                                                                                             | 0.25           | 0.25          | —                |
| Max. flame temperature (°C)                                                                                           | 2155           | 2130          | —                |
| Max. burning velocity (m/s)                                                                                           | 0.45           | 0.38          | —                |
| Necessary min. inert gas conc. for explosion prevention in case of emergent outflow of gas in closed volumes (% v/v): |                |               |                  |
| Nitrogen                                                                                                              | 45             | 41            | —                |
| Carbon dioxide                                                                                                        | 32             | 29            | —                |

from an appliance in which the flame has been extinguished. Any fire near an LPG cylinder may cause it to overheat and catch fire, or result in a BLEVE with missiles projected over long distances.

The following safety measures supplement the general precautions listed in Table 9.3:

Do not store or use a cylinder on its side, but upright with the valve uppermost.

Do not store or leave full or empty cylinders below ground level.

Never change a cylinder without first closing the cylinder valve and extinguishing naked lights in the vicinity.



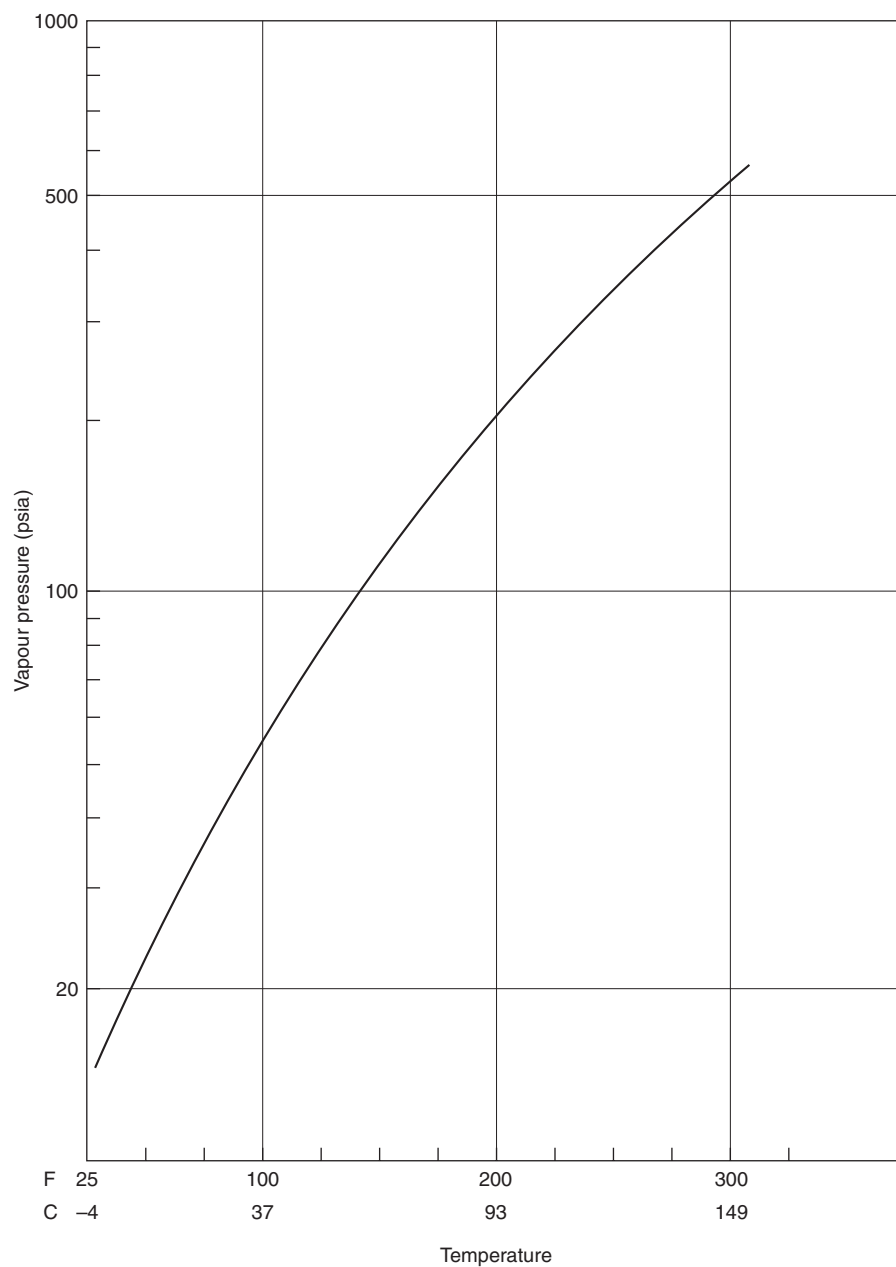


**Figure 9.6** *n*-Butane vapour pressure vs temperature

Store cylinders, both full and empty, in a cool location away from flammable, toxic, or corrosive materials and preferably at least 6.1 m from any source of ignition or heat.

Replace any valve-protecting covers on empty cylinders, or those not in use. Handle cylinders with care.

Unless the installation is designed to be permanent, always disconnect a cylinder after use. Always wear appropriate protective equipment, including gloves and goggles, when filling an LPG cylinder.

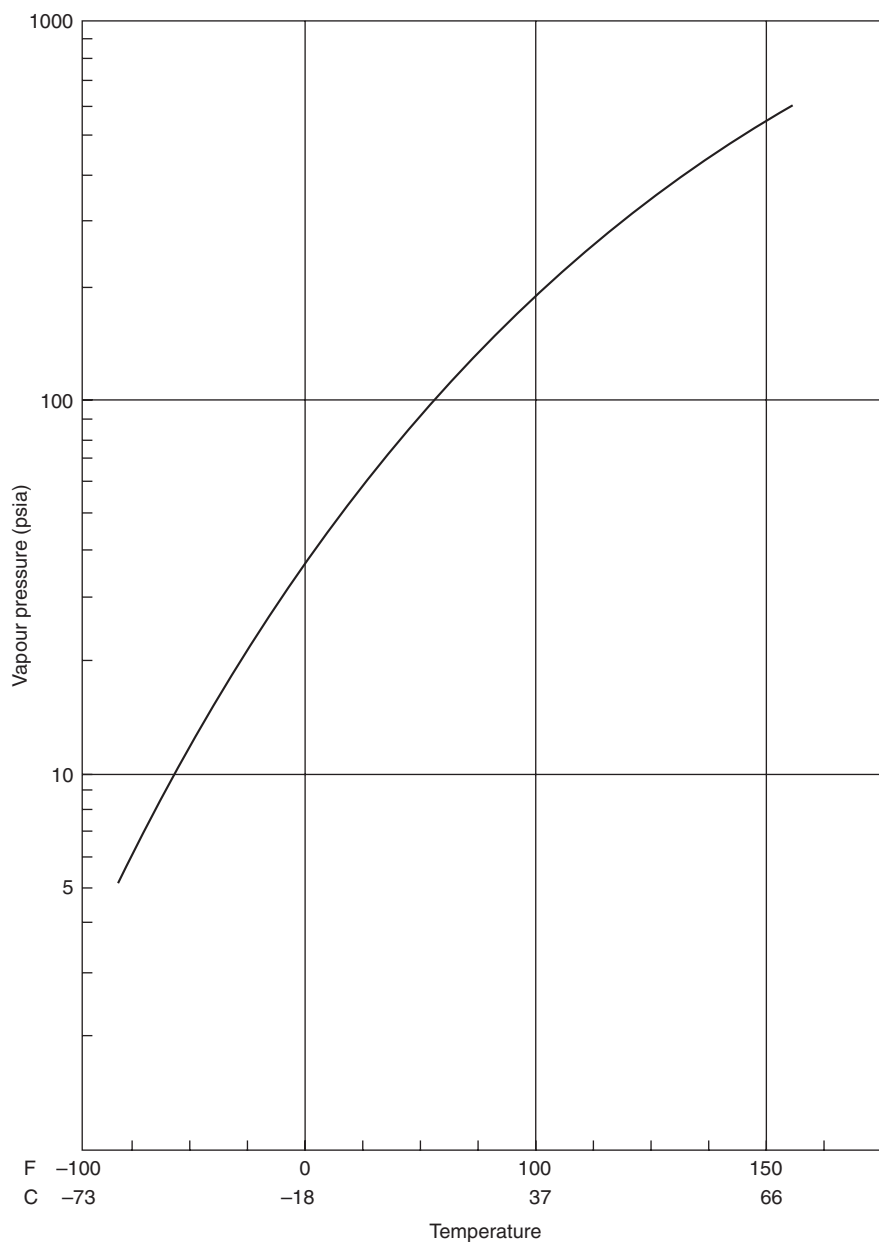


**Figure 9.7** Propane vapour pressure vs temperature

The general requirements for the storage of LPG cylinders are given in Tables 9.16 to 9.18. Considerations in the transport of cylinders by road are given in Chapter 15.

## Methane

Methane is obtained commercially from natural gas wells and from cracking of petroleum fractions.

**Table 9.16 General requirements for storage of LPG cylinders**


---

|                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Store in the open in a well-ventilated area at ground level.                                                                                                                                                                                                                                                                                                                                    |
| Avoid other materials stacked near restricting natural ventilation.                                                                                                                                                                                                                                                                                                                             |
| Flammable liquid and combustible, corrosive, oxidizing or toxic substances and compressed gases should be kept separately.                                                                                                                                                                                                                                                                      |
| Avoid cylinders impeding or endangering means of escape from premises or from adjoining premises.                                                                                                                                                                                                                                                                                               |
| The store floor should be level. A load-bearing surface (concrete, paved or compacted) is required where cylinders are to be stacked.                                                                                                                                                                                                                                                           |
| Security arrangements should be such as to prevent tampering or vandals. Fencing should be of robust wire mesh which does not obstruct ventilation.                                                                                                                                                                                                                                             |
| The area should be at the separation distance from the property boundary, any building or fixed source of ignition quoted in Table 9.17. This may only be reduced if suitable fire-resisting separation is provided.                                                                                                                                                                            |
| To give additional protection from thermal radiation from any cylinder stack fire the minimum separation distance to any nearby building housing a vulnerable population should, for quantities >400 kg, be 8 m or as in Table 9.17, column 3, whichever is the greater. This may be reduced to those in Table 9.17, column 4, by the installation of fire-resisting separation or a fire wall. |
| Prohibit all sources of ignition, including smoking, within a store or within the separation distance (exclude motor vehicles other than fork-lift trucks and those for delivery/collection from open-air stores).                                                                                                                                                                              |
| Avoid openings into buildings, cellars, or pits within 2 m or the separation distances, whichever is greater. (Any gully or drain unavoidably within 2 m should have the opening securely covered or fitted with a water seal to prevent vapour ingress.)                                                                                                                                       |
| Electrical equipment suitable for a Zone 2 area (e.g. to BS 5345) and constructed to a recognized standard should be installed within the store and separation distance. Zone 2 areas are summarized in Table 9.18.                                                                                                                                                                             |
| Clearly mark the area with notices indicating an LPG storage area, flammable contents, prohibition of ignition sources and procedures to follow in case of fire.                                                                                                                                                                                                                                |
| Avoid accumulation of rubbish, small bushes, dry leaves etc. within the separation distance. Remove weeds and long grass within the separation distance and up to 3 m from cylinders.                                                                                                                                                                                                           |
| Cylinders should be stored upright with the valves closed with any protective cover, cap or plug in place. Cartridges without valves may be stored on their sides.                                                                                                                                                                                                                              |
| Cylinders on a vehicle or trailer parked overnight rate as a single stack so that the separation distance in Table 9.17, column 3, is applicable.                                                                                                                                                                                                                                               |
| Cylinders received into store and taken out for delivery should be checked for damage or leakage. Stacks should be inspected daily for stability and that they contain no damaged/leaking cylinders.                                                                                                                                                                                            |
| Cylinders should be handled carefully to avoid personal injury or damage to them.                                                                                                                                                                                                                                                                                                               |

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The physical properties of methane are given in Table 9.19 and the relationship between pressure and temperature in Figure 9.8. It is considered to be non-toxic but is an asphyxiant at high concentrations. Coalminers have inhaled air containing up to 9% methane with no apparent untoward effect but higher concentrations of at least 10% in air result in a feeling of pressure on the eyes and forehead which will disappear after breathing fresh air. Characteristic symptoms of asphyxiation occur at higher concentrations (i.e. rapid respiration, fatigue, nausea, vomiting possibly leading to loss of consciousness and anoxia). At low concentrations the odour of methane is undetectable; at exposures of >5000 ppm there is a sweet oil-type odour. Selected grades contain an odorizer, e.g. natural gas for commercial and domestic full.

It is considered to be chemically inert at room temperature and atmospheric pressure but it does react under more forcing conditions and vigorous reactions have occurred with halogens, interhalogen compounds, and oxidizing agents such as liquid oxygen and dioxygen difluoride.

The main hazard is that of flammability. The following precautions supplement those in Table 9.3 for the storage of methane gas cylinders:

- Store in a purpose-built compound preferably in the open air and well ventilated.
- Locate free from fire risk and away from sources of heat and ignition.
- Maintain clear access, and restrict access to the compound. Mark with hazard warning signs.
- Prohibit the use of naked flames or smoking in the vicinity of, or inside, the compound.

**Table 9.17 Recommended minimum separation distances for total storage of LPG in cylinders or size of maximum stack (the greater of the two distances is advised)**

| (1)<br><i>Total quantity LPG store</i> | (2)<br><i>Size of largest stack</i> | (3)<br><i>Minimum separation distance to boundary, building or fixed ignition sources from the nearest cylinder (where no fire wall provided)</i> | (4)<br><i>Minimum separation distance to boundary, building or fixed ignition source from fire wall (where provided)* **</i> |
|----------------------------------------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| (kg)                                   | (kg)                                | (m)                                                                                                                                               | (m)                                                                                                                          |
| From 15 to 400                         |                                     | 1***                                                                                                                                              | Nil                                                                                                                          |
| " 400 to 1000                          | Up to 1000                          | 3                                                                                                                                                 | 1                                                                                                                            |
| " 1000 to 4000                         |                                     | 4                                                                                                                                                 | 1                                                                                                                            |
| " 4000 to 6000                         | From 1000 to 3000                   | 5                                                                                                                                                 | 1.5                                                                                                                          |
| " 6000 to 12 000                       |                                     | 6                                                                                                                                                 | 2                                                                                                                            |
| " 12 000 to 20 000                     | " 3000 to 5000                      | 7                                                                                                                                                 | 2.5                                                                                                                          |
| " 20 000 to 30 000                     | " 5000 to 7000                      | 8                                                                                                                                                 | 3                                                                                                                            |
| " 30 000 to 50 000                     | " 7000 to 9000                      | 9                                                                                                                                                 | 3.5                                                                                                                          |
| " 50 000 to 60 000                     | " 9000 to 10 000                    | 10                                                                                                                                                | 4                                                                                                                            |
| " 60 000 to 100 000                    |                                     | 11                                                                                                                                                | 4.5                                                                                                                          |
| " 100 000 to 150 000                   | " 10 000 to 20 000                  | 12                                                                                                                                                | 5                                                                                                                            |
| " 150 000 to 250 000                   | " 20 000 to 30 000                  | 15                                                                                                                                                | 6                                                                                                                            |
| Above 250 000                          |                                     | 20                                                                                                                                                | 7                                                                                                                            |

\*The distance from the nearest cylinder to a boundary, building etc. should be not less than in column 3 when measured around the fire wall.

\*\*Minimum distance from nearest cylinder to fire wall should normally be 1.5 m except as qualified.

\*\*\*No separation distance is required for these quantities where boundary walls and buildings are of suitable construction.

**Table 9.18 Areas classified as requiring Zone 2 electrical equipment**

| <i>Location</i>                                                                                        | <i>Extent of classified area</i>                                                                                                                                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Storage in open air                                                                                    | In the storage area up to a height of 1.5 m above the top of the stack or beneath any roof over the storage place.<br>Outside the storage area or the space covered by any roof up to 1.5 m above ground level and within the distance set out for a fixed source of ignition in Table 9.17, column 3. |
| Storage within a specially designed building or in a specially designed storage area within a building | The entire space within the building or storage area and outside any doorway, low level ventilator or other opening into the store within the separation distance set out in Table 9.17, column 3, up to a height of 1.5 m above ground level.                                                         |

Store separately from oxygen and oxidants, using a fire-resistant partition where necessary.

Store the minimum quantity practicable.

Check periodically for general condition and leakage.

## Nitrogen

Nitrogen is an odourless, colourless gas which comprises ca 79% by volume of air and is an essential constituent of all living organisms, e.g. as protein. It is made in the laboratory by gently

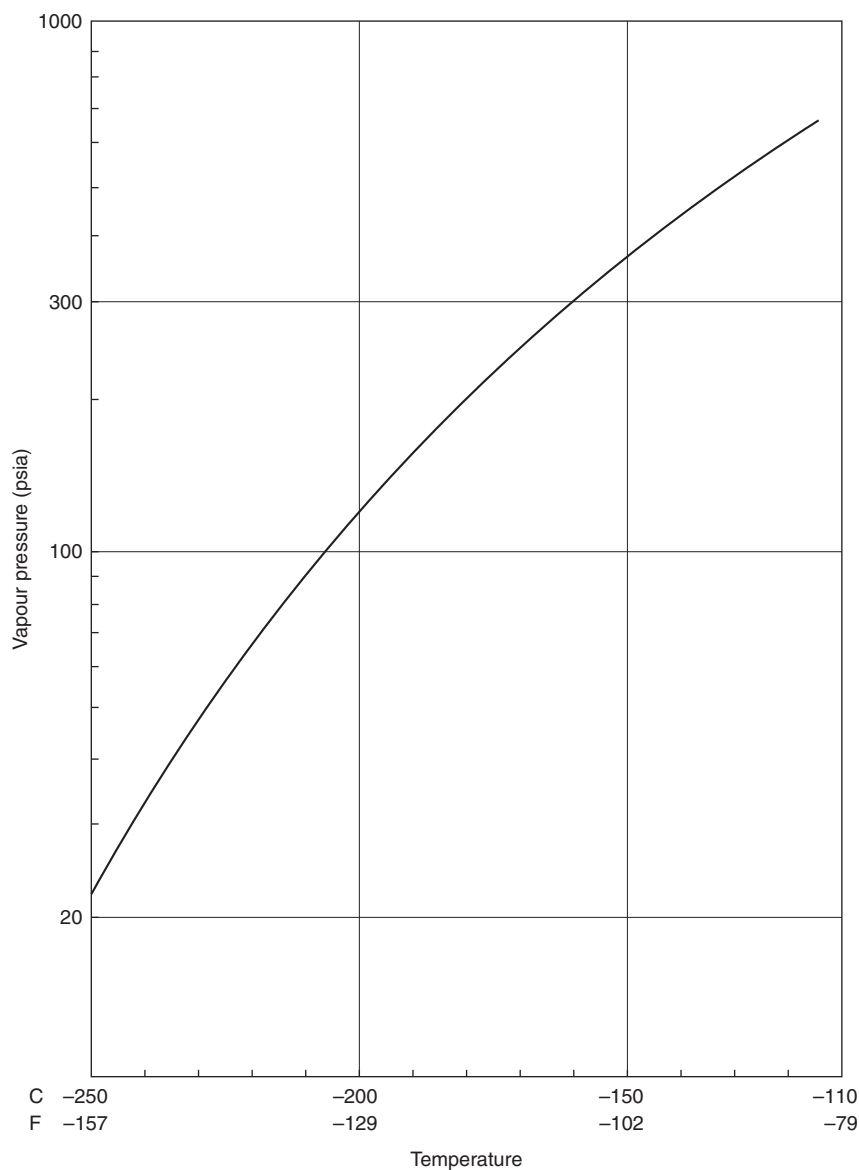
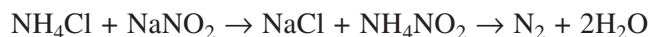


**Figure 9.8** Methane vapour pressure vs temperature

warming a concentrated solution of equimolar proportions of ammonium chloride and sodium nitrite:



On the industrial scale nitrogen is obtained by the fractional distillation of liquid air (see page 261). It will neither burn nor support combustion. Nitrogen is distributed as a pressurized gas in grey cylinders with black shoulders. (Oxygen-free nitrogen has opposed white spots on the cylinder shoulder.) It finds wide use in its inert capacity, e.g. in electrical equipment and in the chemical and food industries. Large volumes of atmospheric nitrogen are converted into ammonium sulphate for fertilizer and into nitric acid.

**Table 9.19 Physical properties of methane**

|                                             |                       |
|---------------------------------------------|-----------------------|
| Molecular weight                            | 16.04                 |
| Specific volume @ 21 C                      | 1479.5 ml/g           |
| Boiling point @ 1 atm                       | -161.5°C              |
| Freezing point @ 1 atm                      | -182.6 C              |
| Triple point                                | -182.5 C              |
| Triple point pressure                       | 0.115 atm             |
| Specific gravity (gas) @ 16 C, 1 atm        | 0.5549                |
| Density (gas) @ 0 C, 1 atm                  | 0.72 g/l              |
| Density (liquid) @ bp                       | 0.4256 g/l            |
| Critical temperature                        | -82.1 C               |
| Critical pressure                           | 673.3 psia (45.8 atm) |
| Critical density                            | 0.162 g/ml            |
| Latent heat of vaporization @ bp            | 121.54 cal/g          |
| Specific heat (gas) @ 16 C, 1 atm $C_p/C_v$ | 1.307                 |
| Flammable limits in air                     | 5.3–14%               |
| Autoignition temperature                    | 540 C                 |
| Minimum ignition energy                     | 0.28 mJ               |
| Flame temperature                           | 1880 C                |
| Limiting oxygen index                       | 11.5%                 |
| Viscosity (gas) @ 1 atm, 4.4 C              | 0.0106 cP             |

Since it is chemically inert no special materials of construction are required. Selected physical properties are listed in Table 9.20.

Nitrogen is non-toxic but will cause asphyxiation through oxygen depletion of air and is the most common cause of gassing accidents in industry. There are no warning signs before unconsciousness occurs, and at high concentrations almost instant unconsciousness may occur and prove fatal (page 77). Table 5.7 summarizes the health effects of oxygen-deficient atmospheres.

## Nitrogen oxides

The various oxides of nitrogen are given in Chapter 5.

Nitrous oxide is a colourless, non-flammable, non-corrosive gas with a sweetish odour and taste. It is prepared both in the laboratory and on a commercial scale by heating ammonium nitrate:



Heating must be terminated when two-thirds of the nitrate has decomposed since explosive nitrogen trichloride may be formed from traces of ammonium chloride impurity.

Nitrous oxide may also be obtained by the controlled reduction of nitrates or nitrites, decomposition of hyponitrites, or thermal decomposition of hydroxylamine.

It is generally considered not to be toxic and non-irritating. One of its main applications is, in combination with air or oxygen, as a weak anaesthetic in medicine and dentistry. At low concentrations it produces hysteria (hence the term laughing gas). At high concentrations in the absence of air it is a simple asphyxiant. It is also used as a dispersing agent in whipping cream.

It does not react with oxygen, ozone, hydrogen, chlorine, potassium, phosphine or aqua regia. However, whilst stable at ordinary temperatures, it decomposes readily to oxygen and nitrogen at 600 C and therefore supports combustion of burning substances. When nitrous oxide is transferred from a stock cylinder to smaller cylinders the gas expansion results in cooling and a reduction in pressure. On heating the stock container to increase pressure and thereby facilitate transfer the gas

**Table 9.20 Physical properties of nitrogen**

|                                   |                     |
|-----------------------------------|---------------------|
| Molecular weight                  | 28.0134             |
| Specific volume @ 21 C            | 861.5 ml/g          |
| Boiling point @ 1 atm             | -195.8 C            |
| Triple point                      | -210.0 C            |
| Triple point pressure             | 94.24 mm Hg         |
| Density (gas) @ 20 C              | 1.250 g/l           |
| Density (liquid) @ bp             | 0.8064 g/ml         |
| Critical temperature              | -147.1°C            |
| Critical pressure                 | 33.5 atm            |
| Critical density                  | 0.311 g/ml          |
| Latent heat of vaporization @ bp  | 47.51 cal/g         |
| Specific heat (gas) @ 16 C, 1 atm |                     |
| $C_p$                             | 0.2477 cal/g C      |
| $C_v$                             | 0.1765 cal/g C      |
| ratio $C_p/C_v$                   | 1.4                 |
| Viscosity (gas) @ 15 C, 1 atm     | 0.01744 centipoises |
| Dielectric constant (liquid) @ bp | 1.433               |
| Solubility in water @ 0 C         | 2.3 ml/100 ml water |

decomposes causing explosive rupture of the stock cylinder. This emphasizes the importance of keeping cylinders away from heat sources, e.g. oxyacetylene welding operations. Explosive reaction has also occurred between nitrous oxide and a variety of chemicals including amorphous boron, ammonia, carbon monoxide, hydrogen, hydrogen sulphide, and phosphine. Because the oxygen content of 36.4% is higher than the 21% in air, combustion or oxidation in nitrous oxide is much faster than in air.

It is transported in high pressure steel cylinders equipped with brass valves.

Physical properties are summarized in Table 9.21 and the vapour pressure/temperature relationship is depicted by Figure 9.9. The general precautions in Table 9.3 apply.

Nitric oxide is made commercially by oxidation of ammonia above 500 C in the presence of platinum, or by reduction of nitrous acid with ferrous sulphate or ferrous halides. The physical

**Table 9.21 Physical properties of nitrous oxide**

|                                      |                             |
|--------------------------------------|-----------------------------|
| Molecular weight                     | 44.013                      |
| Vapour pressure @ 21 C               | 745 psig                    |
| Specific volume @ 21 C, 1 atm        | 543 ml/g                    |
| Boiling point @ 1 atm                | -89.5 C                     |
| Freezing point @ 1 atm               | -90.84 C                    |
| Specific gravity (gas) @ 15 C, 1 atm | 1.530                       |
| Density (gas) @ 0 C, 1 atm           | 1.907 g/l                   |
| Density (liquid) @ bp                | 1.266 g/l                   |
| Critical temperature                 | 36.5 C                      |
| Critical pressure                    | 1054 psia (71.7 atm)        |
| Critical density                     | 0.457 g/l                   |
| Latent heat of vaporization @ bp     | 89.9 cal/g                  |
| Specific heat gas @ 25 C, 1 atm      |                             |
| $C_p$                                | 0.2098 cal/g C              |
| $C_v$                                | 0.1610 cal/g C              |
| ratio $C_p/C_v$                      | 1.3                         |
| Viscosity (gas) @ 0 C, 1 atm         | 0.01362 centipoise          |
| Solubility in water @ 0 C, 1 atm     | 1.3 volumes/volume of water |

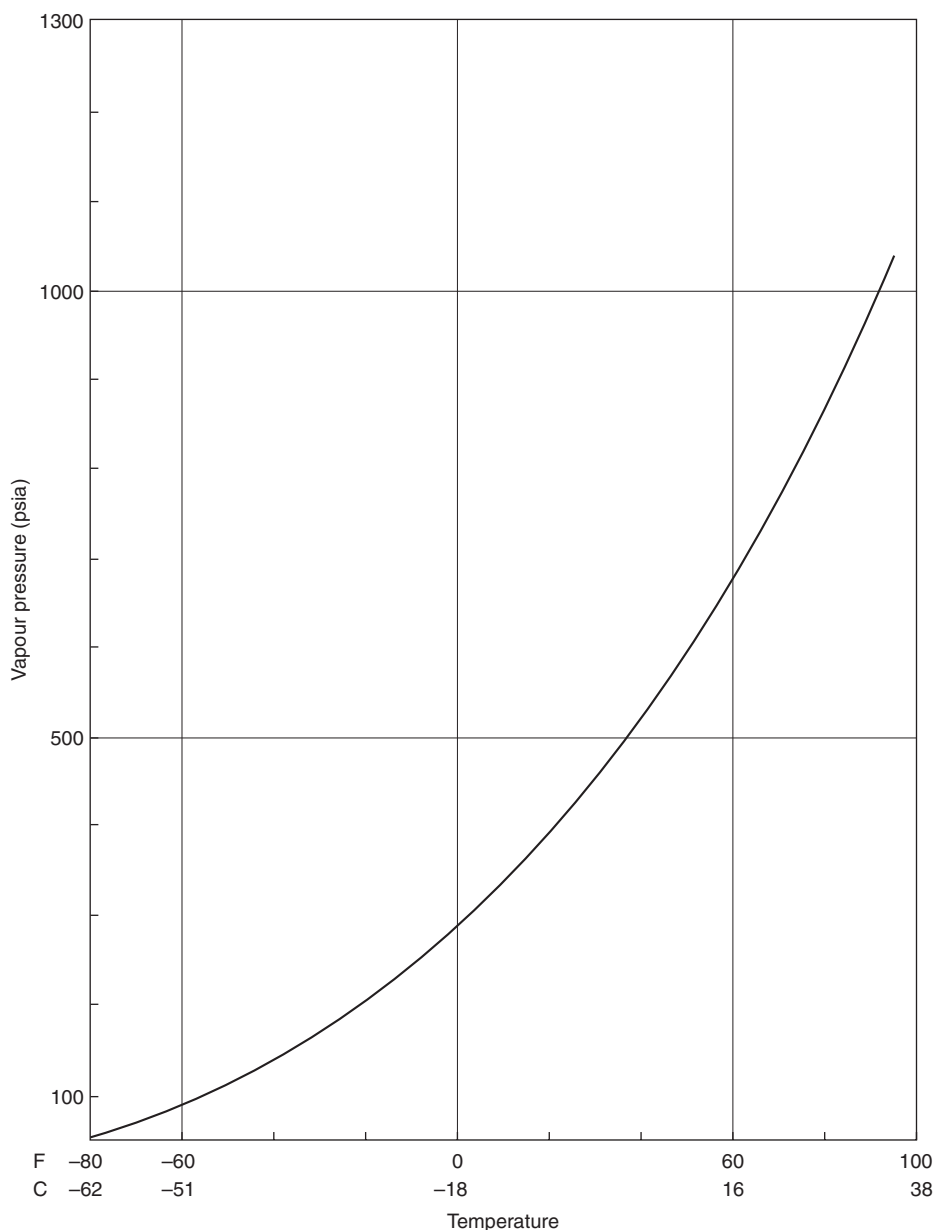


**Figure 9.9** Nitrous oxide vapour pressure vs temperature

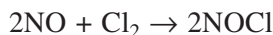
properties of nitric oxide are given in Table 9.22. This is also a colourless, non-flammable gas which is basically non-corrosive to standard materials of construction. Liquid nitric oxide like other cryogenic oxidizers (e.g. ozone) is very sensitive to detonation in the absence of fuel. It is the simplest molecule that is capable of detonation in all three phases: the liquid oxide may explode during distillation. Nitric oxide is more toxic than nitrous oxide. It decomposes into its elements only when heated to 1000 C and therefore it is not a ready supporter of combustion. Vigorously burning phosphorus continues to burn in the gas but burning sulphur or charcoal is extinguished.



Table 9.22 Physical properties of nitric oxide

|                                   |                     |
|-----------------------------------|---------------------|
| Molecular weight                  | 30.006              |
| Specific volume @ 21 C, 1 atm     | 811 ml/g            |
| Boiling point @ 1 atm             | -151.7 C            |
| Freezing point @ 1 atm            | -163.6 C            |
| Density (gas) @ 0 C, 1 atm        | 1.3402 g/l          |
| Density (liquid) @ bp             | 1.269 g/l           |
| Critical temperature              | -93 C               |
| Critical pressure                 | 940.8 psia (64 atm) |
| Critical density                  | 0.52 g/ml           |
| Latent heat of vaporization @ bp  | 110.2 cal/g         |
| Specific heat (gas) @ 15 C, 1 atm |                     |
| $C_p$                             | 0.2328 cal/g C      |
| $C_v$                             | 0.1664 cal/g C      |
| ratio $C_p/C_v$                   | 1.4                 |
| Viscosity (gas) @ 15 C 1 atm      | 0.0178 cP           |
| Solubility in water @ 0 C, 1 atm  | 7.34 ml/100 g water |

Nitric oxide combines readily with atmospheric oxygen at ambient temperature to produce brown fumes of pungent nitrogen dioxide, and in the presence of charcoal with chlorine to form nitrosyl chloride:



It is shipped in cylinders as a non-liquefied gas at a pressure of about 500 psig at 21 C and is primarily used as a chemical intermediate (e.g. in production of nitric acid). It is somewhat soluble in water producing nitric acid, making the gas slightly irritating to the lower reaches of the respiratory system and mucous membranes causing congestion to the throat, bronchi and oedema of the lungs with little warning. The acids neutralize alkali in tissue with subsequent adverse effect on blood pressure, producing headaches and dizziness. The OEL is 25 ppm (8 hr TWA) and 35 ppm (15 min STEL), but generation of the more toxic dioxide on release to air is always a major consideration.

Some special safety measures include:

Handle only in well-ventilated areas, preferable with a hood equipped with forced ventilation. Provide adequate number of exits from the work area.

Use approved personal protection as appropriate, including self-contained breathing apparatus and associated training.

Provide suitable first-aid cover.

Prevent air contamination in high-pressure reactions since the nitrogen dioxide which could form may pose ignition and detonation hazards.

Gaseous nitrogen dioxide is a brown, paramagnetic, non-flammable, toxic, strongly oxidizing, corrosive substance shipped in approved, low-pressure steel cylinders. It is prepared *in situ* by heating lead nitrate:

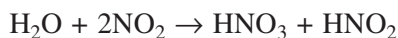


It is available commercially from several routes including as a product from the manufacture of sodium nitrate from sodium chloride and nitric acid, and from a process involving the passage of ammonia and air over heated platinum and treating the nitric oxide so formed with oxygen.

The brown nitrogen dioxide gas condenses to a yellow liquid which freezes to colourless crystals of dinitrogen tetroxide. Below 150 °C the gas consists of molecules of dinitrogen tetroxide and nitrogen dioxide in equilibrium and the proportion of dinitrogen tetroxide increases as the temperature falls. Above 150 °C nitrogen dioxide dissociates into nitric oxide and oxygen.

Nitrogen dioxide is an oxidizing agent; it gives up all, or part, of its oxygen to reducing agents, leaving a residue of nitrogen and nitric oxide. It reacts with potassium, hydrogen sulphide, mercury, burning phosphorus or carbon, heated iron and copper. Explosions have been reported between nitrogen dioxide and a host of materials including alcohols (to produce alkyl nitrates), boron compounds, carbonyl metals, propyl nitrite, nitroaniline dust, sodium amide, triethylamine, and vinyl chloride.

Nitrogen dioxide reacts with water, giving first a mixture of nitrous and nitric acids, and ultimately nitric acid and nitric oxide:



When dry the gas is not corrosive to mild steel at normal temperatures and pressures. Metals and alloys such as carbon steel, stainless steel, aluminium, nickel and Inconel are satisfactory. For wet usage stainless steels resistant to 60% nitric acid are suitable. Important uses include use as a bleaching agent, an oxidation catalyst, polymerization inhibitor, a nitrating agent, oxidizing agent, rocket fuel, and in explosives manufacture. Its physical properties are summarized in Table 9.23 and its vapour pressure/temperature relationship is shown in Figure 9.10.

**Table 9.23 Physical properties of nitrogen dioxide**

|                                          |                                     |
|------------------------------------------|-------------------------------------|
| Molecular weight                         | 46.005 (or 92.01 for the tetroxide) |
| Vapour pressure @ 21 °C                  | 14.7 psia                           |
| Specific volume @ 21 °C, 1 atm           | 293.4 ml/g                          |
| Boiling point @ 1 atm                    | 21.25 °C                            |
| Freezing point @ 1 atm                   | -9.3 °C                             |
| Specific gravity (gas) @ 20 °C, 1 atm    | 1.58                                |
| Density (gas) @ 21 °C, 1 atm             | 3.3 g/l                             |
| Density (liquid) @ 20 °C                 | 1.448 g/ml                          |
| Critical temperature                     | 158.0 °C                            |
| Critical pressure                        | 1470 psia (100 atm)                 |
| Critical density                         | 0.56 g/ml                           |
| Latent heat of vaporization @ bp         | 99.0 cal/g                          |
| Specific heat (gas) @ 25 °C, 1 atm $C_p$ | 0.1986 cal/g °C                     |
| Viscosity (liquid) @ 20 °C               | 4.275 millipoises                   |

A key feature of its toxicity (page 154) at low concentrations is the delay between exposure and onset of symptoms. The OES is 3 ppm (8 hr TWA) and 5 ppm (15 min STEL). Effects of exposure are summarized in Table 5.33. Chronic exposures to low concentrations may cause chronic irritation of the respiratory tract with cough, headache, loss of weight, loss of appetite, dyspepsia, corrosion of the teeth and gradual loss of strength. Concentrations above 60 ppm produce immediate irritation of the nose and throat with coughing, choking, headache, shortness of breath and restlessness. Even brief exposures above 200 ppm may prove fatal. Liquid nitrogen dioxide (dinitrogen tetroxide) is corrosive to skin.

First-aid measures include removal from the contaminated atmosphere, rest and administration of pure oxygen. Skin or eyes in contact with liquid should be thoroughly irrigated. Medical attention should be sought. Other special precautions include:

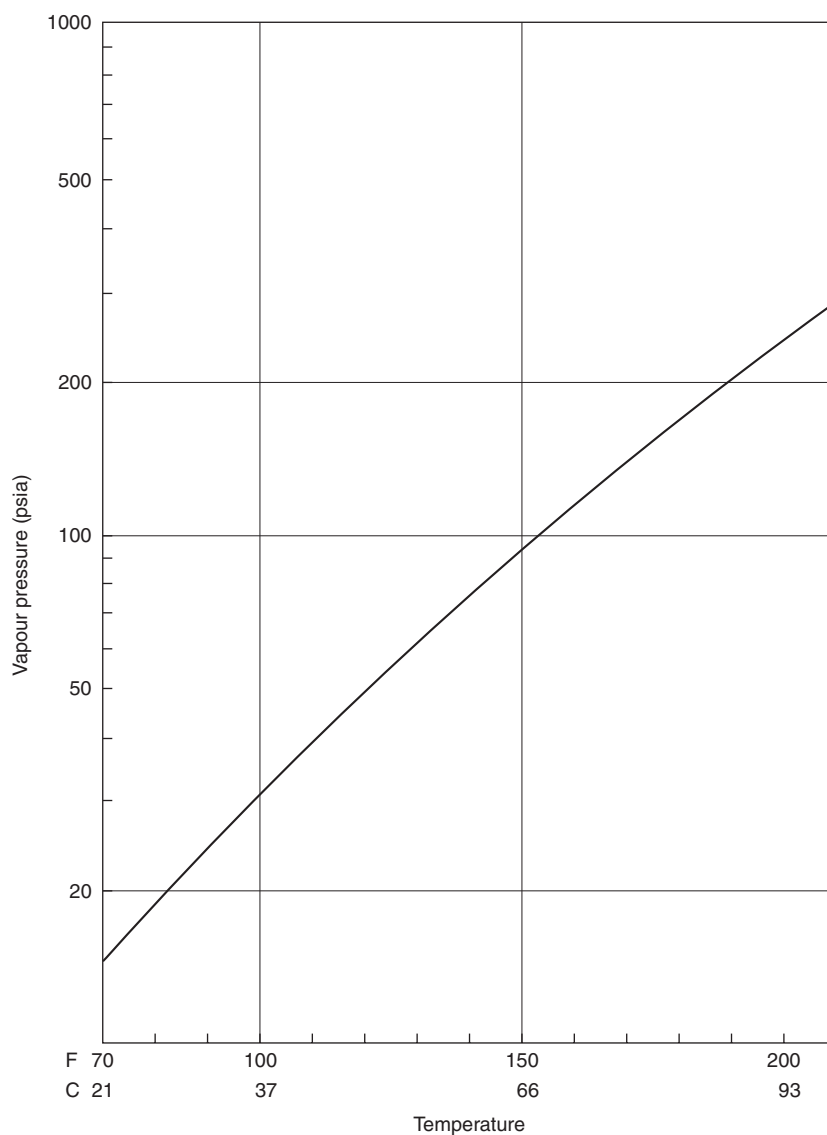


**Figure 9.10** Nitrogen dioxide vapour pressure vs temperature

Handle in well-ventilated area, preferably with hood equipped with forced extract ventilation. Ensure adequate number of emergency exits.

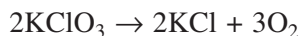
Consider the need for personal protection such as skin, eye (goggles/face shield) and respiratory protection including self-contained breathing apparatus.

Provide instant-acting safety showers and eye-wash facilities in the location of the work area.

Train staff in appropriate first-aid measures including how to seek immediate medical assistance.

## Oxygen

Oxygen occurs free in air in which it forms 21% by volume. It is also found combined with hydrogen in water and constitutes 86% of the oceans, and with other elements such as minerals constituting ca 50% of the earth's crust. In the laboratory it is usually prepared by the thermal decomposition of potassium chlorate in the presence of manganese dioxide catalyst:



Industrially, it is manufactured either by fractional distillation of air, or by electrolysis of sodium hydroxide and it is distributed as a non-liquefied gas in pressurized black cylinders at ca 2200 psig at 21 °C. Since it is non-corrosive no special materials of construction are required.

Selected physical properties of oxygen are included in Table 9.24. It is a colourless, odourless and tasteless gas which is essential for life and considered to be non-toxic at atmospheric pressure. It is somewhat soluble in water and is slightly heavier than air. Important uses are in the steel and glass industries, oxyacetylene welding, as a chemical intermediate, waste-water treatment, fuel cells, underwater operations and medical applications.

**Table 9.24 Physical properties of oxygen**

|                                    |                           |
|------------------------------------|---------------------------|
| Molecular weight                   | 32.00                     |
| Specific volume @ 21 °C, 1 atm     | 755.4 ml/g                |
| Boiling point @ 1 atm              | -183.0°C                  |
| Triple point                       | -218.8 °C                 |
| Density (gas) @ 0 °C, 1 atm        | 1.4291 g/l                |
| Density (liquid) @ bp              | 1.141 g/l                 |
| Critical temperature               | 1118.4 °C                 |
| Critical pressure                  | 737 psia (50.14 atm)      |
| Critical density                   | 0.427 g/l                 |
| Latent heat of vaporization @ bp   | 50.94 cal/g               |
| Specific heat (gas) @ 15 °C, 1 atm |                           |
| $C_p$                              | 0.2200 cal/g °C           |
| $C_v$                              | 0.1554 cal/g °C           |
| ratio $C_p/C_v$                    | 1.42                      |
| Viscosity (gas) @ 25 °C, 1 atm     | 0.02064 centipoise        |
| Solubility in water @ 0 °C, 1 atm  | 1 volume/21 volumes water |

Explosive reactions can occur between oxygen and a wide range of chemicals including organic compounds (such as acetone, acetylene, secondary alcohols, hydrocarbons), alkali and alkaline earth metals, ammonia, biological specimens previously anaesthetized with ether, hydrogen and foam rubber.

Oxygen supports combustion and the hazard is increased if the concentration in air exceeds 21% (page 199) or at pressures above atmospheric pressure. Substances ignite more readily, burn at a faster rate, generate higher temperatures and may be extremely difficult to extinguish. Substances, e.g. plastics, clothing or metals, which may not normally burn easily can burn vigorously in oxygen-enriched air. Oxygen may become trapped within clothing; this can then be ignited and cause serious burn injuries. Because some substances, e.g. oil and grease, may react explosively with pressurized oxygen it is important never to use lubricants on oxygen equipment and to free pipelines from deposits of them.

Enrichment of the atmosphere in any workplace to about 25% oxygen can be hazardous; this is particularly so in a confined space. Inhalation of 100% oxygen at atmospheric pressure for

16 hr per day for several days poses no undue problems but longer periods of exposure to high pressures can adversely affect neuromuscular coordination and the power of concentration.

In addition to the control measures given in Table 9.3, the following precautions are appropriate when using industrial and medical oxygen, or mixtures of oxygen with other gases.

Never:

- Use oxygen to sweeten the air of a workplace.
- Use oxygen instead of fresh air to ventilate or cool a confined space.
- Use oxygen instead of compressed air or as a source of pressure, e.g. to clear blockages in pipelines or to power air-driven tools.
- Use oxygen to blow down clothing, benches or machinery.
- Use oxygen to inflate vehicle tyres, rubber boats etc.
- Use oxygen to start a diesel engine.
- Use oxygen to cool the person.
- Use oil or grease on oxygen equipment.
- Use jointing compound or tape to cure leaks in oxygen equipment, e.g. at cylinder connections.
- Cut off the supply of oxygen by nipping or kinking flexible hose when changing equipment.

Always:

- Only use materials and equipment which are suitable for oxygen service and to a recognized standard.
- Regularly check equipment for signs of leaks, e.g., at hose connections; replace damaged or worn items. Usually the system is pre-tested with, e.g., nitrogen.
- Ensure that equipment, e.g. pipework for oxygen service, is kept clean and free from oil, grease or dust.
- Ensure that the rated maximum inlet pressure of the regulator is not less than the cylinder supply pressure. (For cylinder pressures up to 200 bar, pressure regulators should comply with BS 5741. For higher cylinder pressures check with the manufacturer that the pressure regulator has been shown to be suitable by appropriate testing.)
- Ensure that the pressure adjusting screw of a pressure regulator is fully unwound, so that the regulator outlet valve is closed before opening the oxygen cylinder valve.
- Open cylinder valves slowly.
- Ensure that the cylinder valves are closed and piped supplies isolated whenever work is stopped.
- Ensure that flexible oxygen hose for welding etc. complies with BS 5120. The correct colour for oxygen is blue.
- Ensure that proper fresh air ventilation is provided in oxy-fuel gas welding and cutting operations.
- Ensure that high-pressure oxygen systems are designed, constructed, installed and commissioned by competent people with specialized knowledge of the subject.
- When working on ships, remove pipes or hoses when work stops, other than for short intervals.
- Store oxygen cylinders in a well-ventilated area or compound away from combustible materials and separated from cylinders of flammable gases.
- Handle oxygen cylinders carefully, preferably using a purpose-built trolley and keep secured to prevent cylinders from falling.
- Wear protective clothing appropriate to the work, e.g. leather gloves, fire-retardant overalls, safety shoes or boots and eye protection.
- If applicable, locate oxygen cylinders outside any confined space and in an area of good ventilation.

## Ozone

Ozone is an allotrope of oxygen containing three oxygen atoms. It occurs naturally in the upper atmosphere and is formed in small quantities during electrical discharges from electrical machines or when white phosphorus smoulders in air. In the laboratory it is most conveniently obtained by subjecting air to electrical discharges in 'ozonizers' when some of the oxygen molecules dissociate into oxygen atoms which then combine with other oxygen molecules. However, the yield of ozone is only 10% even when pure oxygen is used. It may also be prepared by electrolysis of ice-cold dilute sulphuric acid using a high current density. Here the concentration of ozone liberated at the platinum-in-glass anode is about 14%.

Pure ozone is made by fractional distillation of the blue liquid resulting from the cooling of ozonized oxygen in liquid air. Commercially it is often supplied dissolved in chlorofluorocarbons in stainless steel cylinders at ca 475 psig cylinder pressure at 20 °C often transported chilled with dry ice. These solutions can be handled safely at vapour concentrations of ca 20% by volume of ozone.

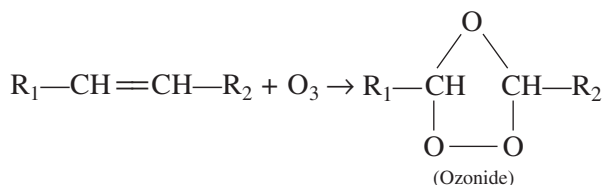
The physical properties of ozone are summarized in Table 9.25.

**Table 9.25 Physical properties of ozone**

|                                        |                              |
|----------------------------------------|------------------------------|
| Molecular weight                       | 47.998                       |
| Boiling point @ 1 atm                  | -111.9 °C                    |
| Freezing point @ 1 atm                 | -192 °C                      |
| Density (gas) @ 0 °C, 1 atm            | 2.143 g/l                    |
| Density (liquid) @ -183 °C             | 1.571 g/l                    |
| Critical temperature                   | -12.1 °C                     |
| Critical pressure                      | 802.6 psia (54.6 atm)        |
| Viscosity (liquid) @ -183 °C           | 1.57 cP                      |
| Latent heat of vaporization @ bp       | 3410 cal/mole                |
| Dielectric constant (liquid) @ -183 °C | 4.79                         |
| Dipole moment                          | 0.55D                        |
| Solubility in water @ 0 °C, 1 atm      | 0.494 volume/volume of water |

Ozone is strongly exothermic in its reactions and neat solid or liquid phases are highly explosive.

Pure ozone is a toxic, slightly bluish, unstable, non-flammable but potentially explosive gas with a smell akin to that of much-diluted chlorine. It is used mainly because of its extreme oxidizing ability (second only to fluorine in oxidizing power) in chemical syntheses or because of its powerful germicidal activity on many bacterial organisms, e.g. as a water purification agent (e.g. swimming pools) although it may leave an unpleasant taste, as a bleach, in treatment of industrial waste, sterilization of air (e.g. in the ventilation of premises of underground railways with limited access to fresh air), deodorizing sewage and stack gases, and in food preservation. Indeed, algae and certain fungi resistant to chlorine are highly susceptible to ozone. It decomposes slowly at room temperature and rapidly at 200 °C and is decomposed by many finely-divided metals. It reacts readily with unsaturated organic moieties to form ozonides:



where  $R_1$  and  $R_2$  are univalent organic groups.

Violent reactions have occurred between ozone and many chemicals, a small selection being acetylene, alkenes, dialkyl zincs, benzene/rubber solution, bromine, carbon monoxide and ethylene, diethyl ether, hydrogen bromide, and nitrogen oxide.

Ozone is an irritant to eyes and mucous membranes. Inhalation can cause pulmonary oedema and bleeding at 'high' concentrations, whilst at lower exposures symptoms include headache, shortness of breath, or drowsiness. Long-term effects may include chronic pulmonary effects, ageing, and possibly lung cancer. The ACGIH classify ozone as one of those 'Agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of the lack of data. In vitro or animal studies do not provide indications of carcinogenicity which are sufficient to classify the agent into one of the other categories.' The TLV is set as a sliding scale for exposures during different workloads, thus:

0.05 ppm for heavy work.

0.08 ppm for moderate work.

0.10 ppm for light work.

0.20 ppm for heavy, moderate, or light workloads for up to a maximum exposure of 2 hours.

Because of the odour threshold of ca 0.015 ppm, exposure to ozone below the TLV can usually be detected by smell.

Precautions in addition to those in Table 9.3 include:

Keep cylinders chilled (to help prevent decomposition rather than as a safety measure).

Avoid copper and copper alloys since these can catalyse the decomposition, and rubber components are unsuitable.

Pre-test systems for leaks with inert gas.

Prevent contact with grease, oil or other combustible material.

Clean all equipment for oxygen service.

Handle in a ventilated hood to protect surrounding atmosphere from leaks.

Consider the need for appropriate personal protection including eye, skin and respiratory equipment.

Consider the need for leak detection systems.

Where possible avoid explosions by working with dilute solutions at low temperatures in suitable solvents.

## Sulphur dioxide

Sulphur dioxide is used as a preservative for beer, wine and meats; in the production of sulphites and hydrosulphites; in solvent extraction of lubricating oils; as a general bleaching agent for oils and foods; in sulphite pulp manufacture; in the cellulose and paper industries; and for disinfection and fumigation.

It is a non-flammable colourless gas which is twice as dense as air, and slightly soluble in water forming sulphurous acid. It is readily liquefied as a gas under its own vapour pressure of about 35 psig (2.4 bar) at 21 °C. Figure 9.11 depicts the effect of temperature on vapour pressure; Table 9.26 lists the physical properties. Cylinders tend to be protected against over-pressurization by metal plugs melting at about 85 °C.

Gaseous sulphur dioxide is highly irritant and practically irrespirable. Effects on the body are summarized in Table 5.3. It can be detected at about 3.5 ppm and the irritating effects would

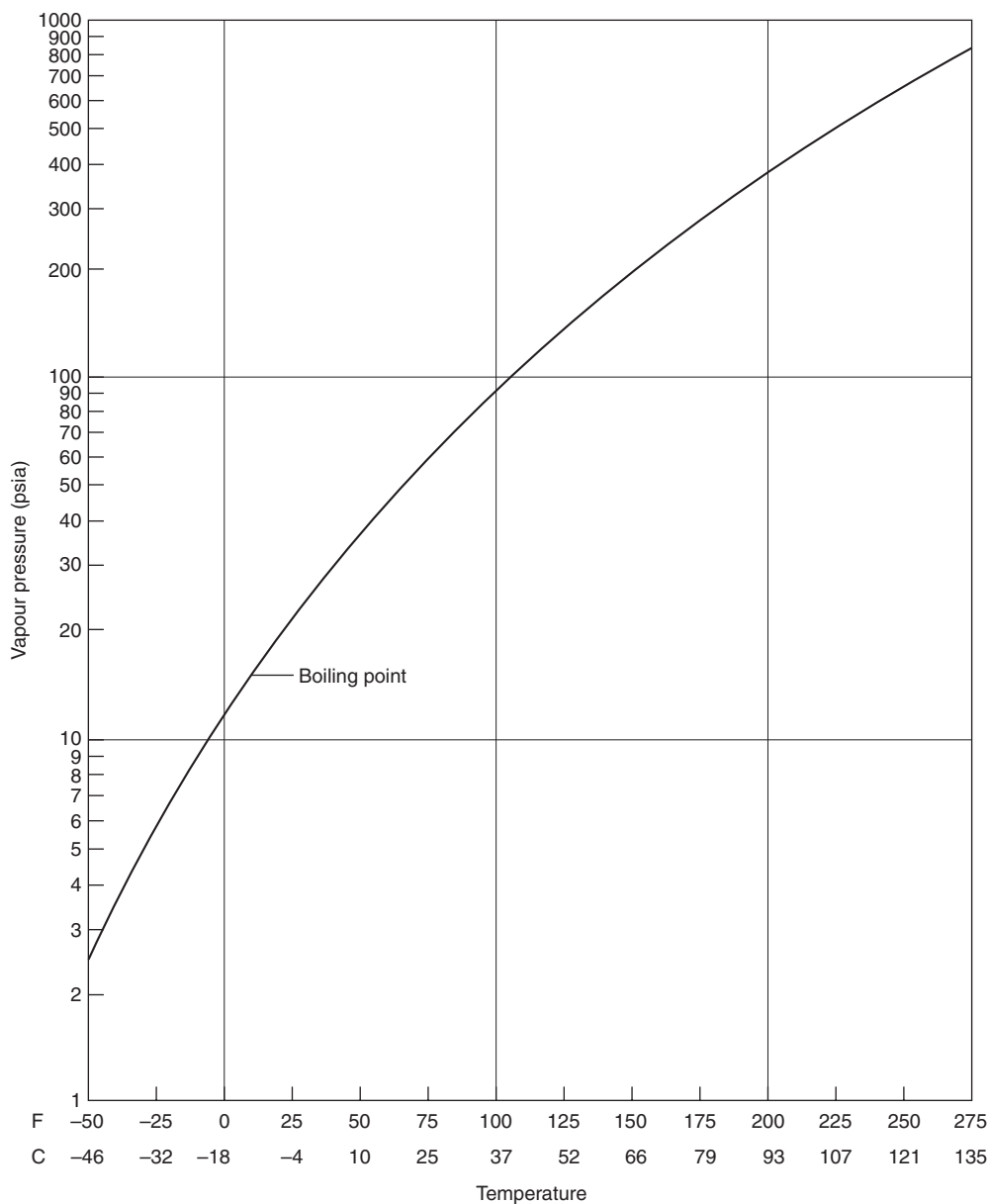


**Figure 9.11** Sulphur dioxide vapour pressure vs temperature

preclude anyone from suffering prolonged exposure at high concentrations unless unconscious, or trapped.

Liquid sulphur dioxide may cause eye and skin burns resulting from the freezing effects upon evaporation. Dry sulphur dioxide is non-corrosive to common materials of construction except zinc. The presence of moisture renders the environment corrosive.

In addition to the precautions listed in Table 9.3, the following controls are appropriate:

Use in well-ventilated areas.



**Table 9.26 Physical properties of sulphur dioxide**

|                                                |                                                   |
|------------------------------------------------|---------------------------------------------------|
| Molecular weight                               | 64.063                                            |
| Vapour pressure at 21 °C                       | 2.37 bar                                          |
| Specific volume at 21 °C, 1 atm                | 368.3 ml/g                                        |
| Boiling point at 1 atm                         | -10.0 °C                                          |
| Freezing point at 1 atm                        | -75.5 °C                                          |
| Specific gravity, gas at 0 °C, 1 atm (air = 1) | 2.264                                             |
| Density, gas at 0 °C, 1 atm                    | 2.927 g/l                                         |
| Density, liquid at -10 °C                      | 1.46 g/ml                                         |
| Critical temperature                           | 157.5 °C                                          |
| Critical pressure                              | 78.8 bar                                          |
| Critical density                               | 0.524 g/ml                                        |
| Latent heat of vaporization at boiling point   | 92.8 cal/g                                        |
| Latent heat of fusion at melting point         | 27.6 cal/g                                        |
| Specific heat, liquid at 0 °C                  | 0.318 cal/g °C                                    |
| Specific heat, gas at 25 °C, 1 atm             |                                                   |
| $C_p$                                          | 0.1488 cal/g °C                                   |
| $C_v$                                          | 0.1154 cal/g °C                                   |
| ratio $C_p/C_v$                                | 1.29                                              |
| Thermal conductivity at 0 °C                   | $2.06 \times 10^{-5}$ cal/s cm <sup>2</sup> °C/cm |
| Viscosity, gas at 18 °C, 1 atm                 | 124.2 mP                                          |
| Solubility in water at 0 °C, 1 atm             | 18.59% by weight                                  |
| at 20 °C, 1 atm                                | 10.14% by weight                                  |

Wear eye/face protection, approved footwear and rubber gloves.

Showers and eye-wash facilities and respiratory protection should be conveniently located for emergencies.

Insert traps in the line to avoid liquid suck-back into the cylinder.

Check for leaks with soap solution, aqueous ammonia or colour indicator tubes.

First aid measures include those in Table 9.9.

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# Monitoring techniques

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As mentioned in Chapters 4, 5 and 16 chemicals can be a nuisance or pose safety, health and environmental risks, or become wasteful of expensive resources if allowed to escape excessively and uncontrollably into the general or workplace environment. Escapes can result from inadequate process control, errors in operation or maintenance, incomplete understanding of the process, etc. Such problems can arise from both: periodic emissions of chemicals due to the need to open, or enter, the 'system' occasionally (e.g. during sampling, cleaning, line-breaking) including both planned and unplanned releases (e.g. due to accidents, human error) and, continuous low-level fugitive emissions from normally-closed points, e.g. valve seals, flange gaskets, pump seals, drain valves.

The need to monitor the impact of activities involving chemicals on the environment may stem from sound management practice or to satisfy a host of specific legal requirements. Thus, in the UK under the Environmental Protection (Prescribed Substances and Processes) Regulations 1991, operators must apply BATNEEC to prevent or minimize the release of prescribed substances into the environment, or to render harmless any emissions. The prescribed substances for release into the air are given in Table 10.1. No prescribed process may be operated without an authorization from the Environment Agency and air pollutants which must be measured and the frequency of monitoring are set out in the authorization. Compliance with emission limits for municipal waste incineration plants (Table 10.2) also requires monitoring.

**Table 10.1 Prescribed substances for release into the air**

---

|                                                   |
|---------------------------------------------------|
| Oxides of sulphur and other sulphur compounds     |
| Oxides of nitrogen and other nitrogen compounds   |
| Oxides of carbon                                  |
| Organic compounds and partial oxidation compounds |
| Metals, metalloids and their compounds            |
| Asbestos, glass fibres and mineral fibres         |
| Halogens and their compounds                      |
| Phosphorus and its compounds                      |
| Particulate matter                                |

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In addition to pollution episodes, risks may arise due to atmospheric oxygen concentrations fluctuating beyond its normal level of 21% posing health (page 72) or fire hazards. Fire and explosion dangers may also arise from the presence of flammable gases, vapours, or dusts in the atmosphere (Chapter 6).

Thus, as illustrated by Table 17.13 monitoring emissions of hazardous chemicals into the environment may be required for a variety of reasons such as:

**Table 10.2 Selected emission limits for municipal waste incineration (units: mg/m<sup>3</sup>)**

| Country                            | EU  | EU  | EU  | UK          | UK  |
|------------------------------------|-----|-----|-----|-------------|-----|
| Plant capacity<br>(tonne per hour) | 3   | 1–3 | <1  | >1          | <1  |
| Particulates                       | 30  | 100 | 200 | 30          | 200 |
| CO                                 | 100 | 100 | 100 | 100         | 100 |
| SO <sub>2</sub>                    | 300 | 300 | –   | 300         | 300 |
| Volatile organic<br>compounds      | 20  | 20  | 20  | 20          | 20  |
| HF                                 | 2   | 4   | –   | 2           | –   |
| NO <sub>x</sub> as NO <sub>2</sub> | –   | –   | –   | 350         | –   |
| Cr, Cu, Mn, Pb                     | 5   | 5   | –   |             |     |
| Ni, As                             | 1   | 1   | –   | 1 (incl Sn) | 5   |
| Cd, Hg                             | 0.2 | 0.2 | –   | 0.1 each    |     |
| Dioxins                            | –   | –   | –   | 1           |     |

Assessing fire or explosion risks from atmospheres containing flammable gas, vapour or dust.

Determining oxygen content of the working atmosphere.

Determining sources of leaks of toxic, flammable, or nuisance pollutants.

Identifying unknown pollutants.

Assessing process efficiency and control.

Assessing environmental risk from effluent discharges or for formal environmental impact assessment.

Determining employee exposure to known toxic substances.

Providing data for internal company environmental audits.

Investigation of the causes of accidents.

Investigation of the cause and nature of problems (e.g. local complaints of odour) or pollution incidents.

## Selected general analytical techniques for monitoring environmental pollution

Stages in environmental monitoring include obtaining representative samples of the environment in question and subsequent analysis of physical, chemical or microbiological attributes. Monitoring techniques range from sophisticated in-line, continuous sampling and instantaneous analysis linked to audible/visual alarms or features to control the pollution; samplers running continuously, e.g. throughout a normal day for subsequent analysis; to grab samples (i.e. samples collected over a short time span of, e.g., a few minutes). Continuous monitoring is common in personal dosimetry studies where an appropriate collection device samples air wherever a worker is throughout a specified period, e.g. 15 minutes or 8 hours (page 111). A selection of common analytical techniques include the following.

### Gases and vapours

#### *Atomic absorption/emission spectrometry*

Metal ions are most commonly measured using atomic absorption spectrometry. In this technique

the test sample is aspirated into a flame where chemical reduction of metal ions to metal atoms occurs. Light is emitted at the discrete absorption wavelength for the metal. A disadvantage is the need for a separate lamp for each element. Emission spectrometry is therefore preferred. Here test material is heated and vaporized using a DC or inductively-coupled plasma generator, after which an optical emission spectrum as a function of wavelength is recorded. An advantage of this technique is that a range of metals or metalloids can be analysed simultaneously.

### *Chemiluminescence*

Here a chemical reaction produces a molecule with electrons in an excited state. Upon decay to the ground state the liberated radiation is detected. One such example is the reaction between ozone and nitric oxide to form nitrogen dioxide emitting radiation in the near infra-red in the 0.5–3  $\mu$ m region. The technique finds use for measuring nitric oxide in ambient air or stack emissions.

### *Chromatography*

This technique permits the separation of a mixture of compounds by their partition between two immiscible heterogeneous phases, one of which is stationary. It detects substances qualitatively and quantitatively. The chromatogram retention time is compound-specific, and peak-height indicates the concentration of pollutant in the sample. Detection systems include flame ionization, thermal conductivity and electron capture. With gas chromatography the mixtures to be separated are in the vapour phase under the operating conditions of the equipment. A gas is used as the mobile phase to carry the sample over a column of stationary phase. Flame ionization detection operates by ionisation of molecules in a hydrogen flame and detection of the current change using a pair of biased electrodes. The current signal is directly related to the number of carbon atoms in the sample. Thermal conductivity detectors measure the change in electrical resistance of a heated filament as gas flows over it. It is most suitable for gases with very high, or very low, conductivity. Traditionally gas chromatography is a laboratory analysis but portable versions are now available for field work.

In classical liquid chromatography a solution of solute percolates under gravity through a column packed with finely-divided solid when different compounds elute at different rates. In high-performance liquid chromatography (HPLC) the liquid is eluted from a packed column under high pressure using solvent. Detection systems include differential refractive index, diode array, electrochemical and ultra-violet-visible absorption. HPLC is used for analysis of less volatile compounds in liquid samples than those in gas chromatography.

Because of its sensitivity (<1 ppm), ion chromatography has become extremely popular for analysis of ions in solution. It is a column-based method for separating ions similar to HPLC but using ion exchange columns and either high- or low-conductivity eluent. The most common detectors are electrical conductivity and ultra-violet absorption. It finds wide use in air pollution monitoring of rain waters, impinger solutions and filter extracts for anions such as sulphate, nitrate, chloride, and cations, including ammonia and metals.

### *Colorimetry*

Use is made of colour changes resulting from reaction of pollutant and chemical reagents: colour intensity indicates concentration of pollutant in the sample. Reaction can take place in solution or on solid supports in tubes or on paper strips, e.g. litmus or indicator paper. Quantitative assessment of colour formation can also be determined using visible spectroscopy. Instruments are calibrated

such that colour intensity is directly related to concentration of contaminant in the test sample. Arguably the technique could also embrace simple acid-base titrations which utilize colour indicators to determine the end-point.

### ***Electrochemical techniques***

In electrochemical cells sample oxidation produces an electric current proportional to the concentration of test substance. Sometimes interferences by other contaminants can be problematic and in general the method is poorer than IR. Portable and static instruments based on this method are available for specific chemicals, e.g. carbon monoxide, chlorine, hydrogen sulphide.

Coulometry measures the amount of current flowing through a solution in an electrochemical oxidation or reduction reaction and is capable of measuring at ppm or even ppb levels of reactive gases. Thus a sample of ambient air is drawn through an electrolyte in a cell and the required amount of reactant is generated at the electrode. This technique tends to be non-specific, but selectivity can be enhanced by adjustment of pH and electrolyte composition, and by incorporation of filters to remove interfering species.

Ion-selective electrodes are a relatively cheap approach to analysis of many ions in solution. The emf of the selective electrode is measured relative to a reference electrode. The electrode potential varies with the logarithm of the activity of the ion. The electrodes are calibrated using standards of the ion under investigation. Application is limited to those ions not subject to the same interference as ion chromatography (the preferred technique), e.g. fluoride, hydrogen chloride (see Table 10.3).

**Table 10.3 Examples of applications of ion-selective electrodes**

| <i>Electrode</i> | <i>Measurement range (ppm)</i> | <i>Major interference</i>                                                           |
|------------------|--------------------------------|-------------------------------------------------------------------------------------|
| Ammonia          | 0.01–17 000                    | Ionic – none                                                                        |
| Bromide          | 0.08–80 000                    | CN <sup>-</sup> , I <sup>-</sup> , S <sup>2-</sup>                                  |
| Chloride         | 0.35–3500                      | CN <sup>-</sup> , I <sup>-</sup> , Br <sup>-</sup> , S <sup>2-</sup>                |
| Cyanide          | 0.003–2600                     | I <sup>-</sup> , S <sup>2-</sup>                                                    |
| Fluoride         | 0.02–1900                      | OH <sup>-</sup>                                                                     |
| Iodide           | 0.013–127 000                  | CN <sup>-</sup> , S <sup>2-</sup>                                                   |
| Nitrate          | 0.6–62 000                     | I <sup>-</sup> , Br <sup>-</sup> , SCN <sup>-</sup> , ClO <sub>4</sub> <sup>-</sup> |
| Sulphide         | 0.32–32 100                    | Ag <sup>+</sup> , Hg <sup>+</sup>                                                   |

### ***Infra-red spectroscopy***

The basis of this technique is absorption of IR radiation by molecules over a wide spectrum of wavelengths to give a characteristic 'fingerprint' spectrum providing both qualitative and quantitative data on the substance. This versatile technique owes its success in occupational hygiene to the development of a portable spectrometer of the non-dispersive type which focuses on specific parts of the spectrum in which the pollutant shows peak absorption as opposed to scanning the entire spectrum. Table 10.4 identifies principal absorption peaks for selected gases. One advantage of IR is that the detector does not 'react' with the gases and the major functional components are protected and easily removed for maintenance. Since IR detection is potentially sensitive to temperature, the instrument requires approximately 15 minutes to equilibrate prior to use. Water vapour can seriously affect performance.

**Table 10.4** Main IR absorption peaks for selected gases

| <i>Chemical</i>  | <i>Wavelength (micron)</i> |
|------------------|----------------------------|
| Carbon dioxide   | 4.35                       |
| Carbon monoxide  | 4.60                       |
| Methane          | 3.30                       |
| Nitric oxide     | 5.30                       |
| Nitrogen dioxide | 3.70                       |
| Nitrous oxide    | 4.50                       |
| Sulphur dioxide  | 4.00                       |

### ***Mass spectrometry***

This technique relies on the formation of ions by various means in a high-vacuum chamber, their acceleration by an electrical field and subsequent separation by mass/charge ratio in a magnetic field and the detection of each species. It can be used for both inorganic and organic substances, be very sensitive, and be of value in examining mixtures of compounds especially if linked to glc. Usually this is a laboratory technique but portable or 'transportable' models are now available.

### ***Ultra-violet spectrometry***

Outermost valency electrons in atoms are excited by ultra-violet radiation. The excited electrons return to the ground state liberating energy by disassociation, re-emission, fluorescence, or phosphorescence. The level of UV radiation absorbed follows the Beer–Lambert law (page 312). The peak wavelength for selected gases is given in Table 10.5. Photo ionization detectors (PIDs) use ultraviolet light to ionize gas molecules such as volatile organic compounds; the free electrons collected at electrodes result in a current flow proportional to the gas concentration. The lamp requires constant cleaning and hence may have limited life expectancy.

**Table 10.5** UV wavelengths for selected gases

| <i>Gas</i>        | <i>Wavelength (nm)</i> |
|-------------------|------------------------|
| Ammonia           | 200                    |
| Chlorine          | 280–380                |
| Hydrogen sulphide | 200–230                |
| Nitrogen dioxide  | 380–420                |
| Oxygen/ozone      | 170                    |
| Sulphur dioxide   | 285                    |

### ***Compound specific analysers***

Several instruments are available that are designed to monitor a specific compound rather than a wide range of substances. The detection system varies according to the pollutant. A selection is given in Table 10.6.

**Table 10.6** Selected examples of compound specific instruments

| <i>Compound</i>              | <i>Detection system</i>                                                                                           |
|------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Ammonia                      | Coulometry (e.g. Nessler method)<br>Ion selective electrode<br>Oxidation to NO <sub>x</sub> and chemiluminescence |
| Carbon monoxide              | Polarography<br>Infra-red                                                                                         |
| Chlorine                     | Ultraviolet spectroscopy                                                                                          |
| Hydrogen chloride            | Polarography<br>Ion-selective electrode                                                                           |
| Hydrogen fluoride            | Polarography<br>Colorimetry                                                                                       |
| Inorganic cyanides           | Colorimetry<br>Ion-selective electrode                                                                            |
| Oxides of nitrogen           | Chemiluminescence<br>Coulometry                                                                                   |
| Oxygen                       | Polarography<br>Paramagnetic susceptibility<br>Fluorescence                                                       |
| Ozone                        | Ultraviolet spectroscopy<br>Chemiluminescence<br>Coulometry                                                       |
| Phosgene                     | Ultraviolet spectroscopy                                                                                          |
| Phosphorus and its compounds | Flame photometry                                                                                                  |
| Toluene                      | Ion-mobility spectroscopy                                                                                         |
| Total hydrocarbons           | Flame ionization                                                                                                  |
| Sulphur compounds            | Flame photometry<br>Coulometry<br>UV fluorescence                                                                 |

## Particulates

Samples of particulate matter can be subjected to many of the above analytical techniques in chemical characterization. The following methods are, however, particularly applicable to analysis of physical characteristics of particulate matter isolated from air sampling.

### *Mass concentration*

Simple gravimetry of the sample is likely to be an integral component of the determination of, e.g., the concentration of, or exposures to, airborne dust. Care is required to avoid errors arising from absorption of atmospheric moisture. This can be avoided by using blank filters, by conditioning the filters in an atmospherically-controlled room, or use of a desiccator.

Automatic aerosol mass concentration can be achieved directly by collecting particles on a surface followed by use of a piezoelectric or oscillation microbalance, or by  $\beta$ -attenuation sensing techniques, or indirectly using light scattering. The piezoelectric microbalance contains an electrostatic precipitator to deposit particles onto a vibrating silica crystal. The change in resonance frequency is converted into mass concentration using a microprocessor. Oscillating balances operate on the principle that air at 50 °C (to avoid condensation) passes through a filter attached to the top of a tapered glass tube which vibrates at its natural frequency. As material is deposited on the filter the oscillation frequency changes directly in proportion to the increased mass. Beta gauges rely on the principle that when low-energy  $\beta$  particles pass through a material the intensity of the beam is attenuated according to Beer–Lambert law:

$$I = I_0^{-ux}$$

where  $I$  and  $I_0$  are the initial and attenuated beam intensities,  $u$  is the mass absorption coefficient and  $x$  is the absorber thickness.

### ***Light scattering***

Optical particle counters provide information on the particles present in different size ranges. A beam of light is collimated and focused onto a measurement cell. Light impinging on a particle is scattered and reaches a photomultiplier tube and converted to an output proportional to particle size. Particle size distributions are computed by appropriate software.

### ***Electrostatic sampling***

Particles become positively charged by a corona discharge and travel out of the charging chamber and collect on a substrate such as a microscope slide. Thus, the method is useful for particles which are to be examined by optical or electron microscopy.

### ***Optical microscopy***

This technique is invaluable for measurement of particle size, for counting the number of particles and for identification of particles by:

morphology, e.g. by comparison with standard particles, and refractive index using polarized light microscopy.

### ***Electron microscopy***

With a resolution of 0.01  $\mu\text{m}$  this technique outperforms optical light microscopy (0.1  $\mu\text{m}$ ) and is used, e.g., to examine fine particles such as metal fume. When linked to other facilities such as dispersive X-ray analysis, quantitative data can be obtained.

### ***X-ray techniques***

Crystals produce different diffraction patterns when subjected to bombardment of monochromatic X-ray sources and thereby provide unequivocal identification of crystalline materials.

In X-ray fluorescence incident radiation induces electronic fluorescent emission in most atoms. The effects can be used both qualitatively and quantitatively for metals, alloys etc.

## **Monitoring water quality**

Water is essential to man both directly and indirectly through agriculture and industry in which vast quantities are used for cooling, energy production, irrigation, refrigeration, washing, solvents etc. Risk of contamination can render water dangerous, unpleasant, or unusable. Point sources of water pollution include domestic and industrial waste whilst non-point sources include agricultural and urban run-offs. Analysis of water is important for estimating the nature and concentration of contaminants and hence fitness for use. Artificial contaminants are mainly of domestic and



industrial origin, and are increasing in similarity because of the expanding domestic use of chemicals (cosmetics, detergents, paints, garden insecticides and fertilizers). Water quality can be assessed by direct analysis of chemical substances or by indirect effects, e.g. pH, colour, turbidity, odour, impact on dissolved oxygen content.

Chemical pollutants are classified as inorganic or organic. The former include metals (e.g. Mn, Fe, Cu, Zn, Hg, Cd, As, Cr), anions (e.g.  $\text{Cl}^-$ ,  $\text{SiO}_3^{2-}$ ,  $\text{CN}^-$ ,  $\text{F}^-$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{PO}_4^{3-}$ ,  $\text{SO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{S}^{2-}$ ), and gases ( $\text{Cl}_2$ ,  $\text{NH}_3$ ,  $\text{O}_2$ ,  $\text{O}_3$ ). Methods for the examination of waters and associated materials published by the UK Department of the Environment are listed in Table 10.7. Selected methods for metal analysis are summarized in Table 10.8. Sampling protocols are described in, e.g., BS 6068 and BS EN 2567. Examples of BS methods for analysis of chemical contaminants in water are illustrated by Table 10.9. Biological methods are also given in BS 6068.

## Monitoring land pollution

Sources of land pollution include transport accidents, spillage during chemical handling, loss of containment from storage tanks, leakage and landfill of waste effluent. An appreciation of the processes governing retention, degradation and removal of pollutants and the behaviour of specific pollutants in soil are essential in devising correct sampling and analytical strategies for assessing land contamination. Even soil itself varies in dynamics and composition from one site to another. Constituents include solid phase materials (such as complex mixtures of clays, minerals, organic matter), liquid aqueous phase of solutions (e.g. natural minerals, fertilizers, pesticides and industrial wastes) and gaseous phase components (e.g. oxygen, nitrogen, carbon dioxide, oxides of nitrogen, ammonia, hydrogen sulphide). The determination of toxic elements and organic substances in soils is a requisite of some EC directives as a means of controlling environmental pollution. Analyses are important when certain types of waste are recycled, e.g. by spreading sludge from water purification units on land, composting from household refuse. The choice of analytical method will be dictated by accuracy, sensitivity etc. Some key techniques are summarized in Table 10.10 and selected BS methods for monitoring soil quality are listed in Table 10.11.

## Monitoring air pollution

### *Sampling*

Differences exist between the monitoring of pollution levels in ambient and workplace air. These reflect the differences in levels of contaminant, environmental standards, purposes for which data are used, etc. (see also Table 16.8). Thus, although similarities may exist in detection techniques, the sampling regimes, analytical details and hardware specifications may differ for assessment of the two environments. In general, atmospheric levels of contaminants are much lower in ambient air than those encountered in the workplace. As a result larger volumes of sample are often needed for ambient air analyses. This can be achieved using pumps of larger flow rate capacities, or by longer sampling times.

Atmospheric monitoring involves first obtaining samples of the air with subsequent analysis of the samples collected. Examples of sampling techniques for gases and vapours are given in Table 10.12. Air samples can be pumped into instruments for direct analysis and data readout. Alternatively, they are collected in air-tight bags, or absorbed in liquids, or onto solid sorbents, for subsequent laboratory analysis using techniques such as those described on page 308. Common solid sorbents

**Table 10.7 Methods for the examination of water and associated materials published by the UK Department of the Environment**


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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A review and methods for the use of epilithic diatoms for detecting and monitoring changes in river water quality, 1993                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Chlorophenylid, Flucifuron and Sulcofuron Waters (Tentative Methods based on methylation and GC-ECD, ion-pair HPLC and hydrolysis of Sulcofuron to 4-chloro-3-trifluoromethylaniline by GC-ECD), 1993                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Cyanide in Waters etc. (by Reflux Distillation followed by either Potentiometry using a Cyanide Selective Electrode or Colorimetry, or Continuous Flow Determination of Cyanide or Determination by Microdiffusion), 1988                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Determination of Aldicarb and other <i>N</i> -methyl carbamates in Waters (by HPLC or Confirmation of total Aldicarb residues and other <i>N</i> -methyl carbamates in waters by GC), 1994                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Determination of the pH Value of Sludge, Soil, Mud and Sediment; and the Lime Requirement of Soil (Second Edition) (by Determination of the pH Value of Sludge, Soil, Mud and Sediment or by Determination of the Lime Requirement of Soil), 1992                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Flow Injection Analysis, An Essay Review and Analytical Methods                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Information on Concentration and Determination Procedures in Atomic Spectrophotometry, 1992                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Isolation and Identification of Giardia Cysts, Cryptosporidium Oocysts and Free Living Pathogenic Amoebae in Water etc., 1989                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Kjeldahl Nitrogen in Waters [including Mercury Catalysed Method, Semi-automated Determination of Kjeldahl Nitrogen (Copper Catalysed, Multiple Tube, Block Digestion Method followed by Air Segmented Continuous Flow Colorimetry) Determination of Kjeldahl Nitrogen in Raw and Potable Water (Hydrogen Peroxide, Multiple tube, Block Digestion Method followed by Manual or Air-Segmented Continuous Flow Colorimetry) Semi-automated Determination of Kjeldahl Nitrogen (Copper/Titanium Catalysed, Multiple Tube, Block Digestion Method followed by Distillation and Air Segmented Continuous Flow Colorimetry), Air-segmented Continuous Flow Colorimetric Analysis of Digest Solutions for Ammonia], 1987                                                    |
| Linear Alkylbenzene Sulphonates (LAS) and Alkylphenol Ethoxylates (APE) in Waters, Wastewaters and Sludges by High Performance Liquid Chromatography, 1993                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Phenylurea herbicides (urons), Dinocap, Dinoseb, Benomyl, Carbendazim and Metamitron in Waters [e.g. determination of phenylurea herbicides by reverse phase HPLC, phenylurea herbicides by dichloromethane extraction, determination by GC/NPD, phenylurea herbicides by thermospray LC-MS, Dinocap by HPLC, Dinoseb water by HPLC, Carbendazim and Benomyl (as Carbendazim) by HPLC], 1994                                                                                                                                                                                                                                                                                                                                                                         |
| Phosphorus and Silicon in Waters, Effluents and Sludges [e.g. Phosphorus in Waters, Effluents and Sludges by Spectrophotometry-phosphomolybdenum blue method, Phosphorus in Waters and Acidic Digests by Spectrophotometry-phosphovanadomolybdate method, Ion Chromatographic Methods for the Determination of Phosphorus Compound, Pretreatment Methods for Phosphorus Determinations, Determination of silicon by Spectrophotometric Determination of Molybdate Reactive Silicon-1-amino-2-naphthol-4, sulphonic acid (ANSA) or Metol reduction methods or ascorbic acid reduction method, Pretreatment Methods to Convert Other Forms of Silicon to Soluble Molybdate Reactive Silicon, Determination of Phosphorus and Silicon Emission Spectrophotometry], 1992 |
| Sulphate in Waters, Effluents and Solids (2nd Edition) [including Sulphate in Waters, Effluents and Some Solids by Barium Sulphate Gravimetry, Sulphate in waters and effluents by direct Barium Titrimetry, Sulphate in waters by Inductively Coupled Plasma Emission Spectrometry, Sulphate in waters and effluents by a Continuous Flow Indirect Spectrophotometric Method Using 2-Aminoperimidine, Sulphate in waters by Flow Injection Analysis Using a Turbidimetric Method, Sulphate in waters by Ion Chromatography, Sulphate in waters by Air-Segmented Continuous Flow Colorimetry using Methylthymol Blue], 1988                                                                                                                                          |
| Temperature Measurement for Natural, Waste and Potable Waters and other items of interest in the Water and Sewage Disposal Industry, 1986                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| The Determination of 6 Specific Polynuclear Aromatic Hydrocarbons in Waters [Using High-Performance Liquid Chromatography, Thin-layer Chromatography], 1985                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| The Determination of Taste and Odour in Potable Waters, 1994                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Use of Plants to Monitor Heavy Metals in Freshwaters [Methods based on Metal Accumulation and on Techniques other than Accumulation], 1991                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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**Table 10.8 Methods for analysis of metal content of water**

| <i>Method</i>                                 | <i>Comment</i>                                                                               | <i>Sensitivity</i>                                              |
|-----------------------------------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| Spectrophotometry–Colorimetry                 | One of most useful and versatile methods but can be time consuming                           | $10^{-5}$ to $10^{-7}$ M<br>( $10^{-9}$ with pre-concentration) |
| Kinetic analysis (metal ion acts as catalyst) | Sensitive, highly selective, only needs small samples                                        | $10^{-8}$ to $10^{-9}$ M                                        |
| Atomic absorption spectrophotometry:          |                                                                                              |                                                                 |
| Flame                                         | Simple, versatile; measures total metal content. Knowledge of interfering effects important. | $10^{-6}$ to $10^{-7}$ M                                        |
| Flameless                                     |                                                                                              | $10^{-8}$ to $10^{-9}$ M                                        |
| Flame and spark emission spectroscopy         | Not very accurate. Gives multi-element analyses                                              | $10^{-5}$ to $10^{-8}$ M                                        |
| Neutron activation analysis                   | Specialized, expensive                                                                       | $10^{-9}$ to $10^{-10}$ M                                       |
| Ion-selective electrodes                      | Highly selective but insensitive and imprecise                                               | $10^{-5}$ to $10^{-6}$ M                                        |
| Polarography:                                 | Restricted to electroactive metals                                                           |                                                                 |
| Conventional                                  |                                                                                              | $10^{-5}$ to $10^{-6}$ M                                        |
| Modified                                      |                                                                                              | $10^{-6}$ to $10^{-8}$ M                                        |
| Anodic stripping voltametry                   | Applicable to few metals and dependent on metal speciation                                   | $10^{-8}$ to $10^{-10}$ M                                       |

for gases and vapours (Table 10.13) include silica gel, activated charcoal, or organic resins. Silica gel is most useful for polar compounds whereas charcoal finds wide use for non-polar substances. Subsequently, the pollutant is generally removed from the solid phase by thermal desorption or by solvent extraction. The advantages and disadvantages of the two desorption techniques are summarized in Table 10.14. Their versatility is illustrated by Table 10.15 for use of charcoal.

Pumps vary from large, stationary high-volume versions to pocket-size devices for use in personal dosimetry when operators wear sampling devices in the form of tubes or badges in lapels to collect air sampled in their breathing zone. Passive samplers are also available for monitoring gases and vapours in air. These are inexpensive devices which do not require a mechanical pump but rely on the concentration gradient between the air and sorbent material and the resultant molecular diffusion of the pollutant towards the sorbent according to Fick's law:

$$Q = DdC/dZ$$

where  $Q$  = molar flux ( $\text{mol cm}^{-2}\text{s}^{-1}$ ),  
 $D$  = diffusion coefficient ( $\text{cm}^2\text{s}^{-1}$ ),  
 $C$  = concentration ( $\text{mol cm}^{-3}$ )  
 $Z$  = diffusion path length (cm).

Because of the low rates of molecular diffusion, assessment of workplace air quality using passive samplers usually entails sampling for a working shift, and exposure periods of one to four weeks tend to be needed to measure concentrations in ambient air.

### *Gases and vapours*

Analyses of gases and vapours tend to utilize the techniques described on page 308. Many of these methods were traditionally limited to laboratory analyses but some portable instruments are now available for, e.g., gas chromatography (Table 10.16) and non-dispersive infra-red spectrometry (Table 10.17).

**Table 10.9 Selected British Standard methods for monitoring water quality**

| <i>BS reference</i> | <i>Substance</i>                                                                                                                                       | <i>Method</i>                                                     |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| BS 1427             | General guide to methods for analysis of water                                                                                                         | field and on-site techniques                                      |
| BS 2690             | free EDTA                                                                                                                                              |                                                                   |
|                     | hydrazine                                                                                                                                              | spectrophotometry                                                 |
|                     | silica                                                                                                                                                 |                                                                   |
|                     | cyclohexylamine                                                                                                                                        | spectrophotometry                                                 |
|                     | morpholine                                                                                                                                             | spectrophotometry                                                 |
|                     | long-chain fatty acids                                                                                                                                 | spectrophotometry                                                 |
| BS 6068             | mercury                                                                                                                                                | flameless atomic absorption                                       |
|                     | ammonium                                                                                                                                               | distillation and titration                                        |
|                     | ammonium                                                                                                                                               | potentiometric                                                    |
|                     | ammonium                                                                                                                                               | manual spectrometry                                               |
|                     | phenol index                                                                                                                                           | spectrometric                                                     |
|                     | cyanide                                                                                                                                                | diffusion at pH6                                                  |
|                     | cyanogen chloride                                                                                                                                      |                                                                   |
|                     | ammonium                                                                                                                                               | automated spectrometry                                            |
|                     | nitrate                                                                                                                                                | spectrometry using sulphosalicylic acid                           |
|                     | inorganically bound total fluoride                                                                                                                     | digestion and distillation                                        |
|                     | pH                                                                                                                                                     |                                                                   |
|                     | iron                                                                                                                                                   | photometric                                                       |
|                     | calcium and magnesium                                                                                                                                  | EDTA titrimetric                                                  |
|                     | nonionic surfactants                                                                                                                                   | Dragendorff reagent                                               |
|                     | anionic surfactants                                                                                                                                    | methylene blue titration                                          |
|                     | arsenic, cadmium, cobalt, copper, lead, magnesium, nickel, zinc                                                                                        | atomic absorption spectrometry                                    |
|                     | arsenic (total)                                                                                                                                        | spectrometry                                                      |
|                     | manganese                                                                                                                                              | formaldehyde spectrometry                                         |
|                     | chemical oxygen demand                                                                                                                                 |                                                                   |
|                     | sulphate                                                                                                                                               | barium chloride gravimetry                                        |
|                     | borate                                                                                                                                                 | spectrometry                                                      |
|                     | sodium and potassium                                                                                                                                   | atomic absorption spectrometry and by flame emission spectrometry |
|                     | selenium                                                                                                                                               | atomic absorption spectrometry                                    |
|                     | aluminium                                                                                                                                              | spectrometry                                                      |
|                     | herbicides                                                                                                                                             | gas chromatography and mass spectrometry                          |
|                     | organochlorine compounds                                                                                                                               | gas chromatography                                                |
|                     | dissolved anions (bromide, chloride, nitrate, nitrite, phosphate, sulphate, chromate, iodide, sulphite, thiocyanate, thiosulphate, chlorate, chlorite) | liquid chromatography                                             |
|                     | organic nitrogen and phosphorus                                                                                                                        | gas chromatography                                                |
|                     | 33 elements                                                                                                                                            | inductively coupled plasma atomic emission spectrometry           |
|                     | nitrogen                                                                                                                                               | chemiluminescence                                                 |
|                     | mercury                                                                                                                                                | enrichment by amalgamation                                        |
|                     | free and total chlorine                                                                                                                                | titrimetric or colorimetric                                       |
|                     | chlorophenols                                                                                                                                          | gas chromatography                                                |
|                     | organophosphates                                                                                                                                       | gas chromatography                                                |
|                     | dissolved oxygen                                                                                                                                       | iodometry or electrochemical probe                                |
|                     | phosphorus                                                                                                                                             | spectrometry                                                      |

Table 10.9 Cont'd

| <i>BS reference</i> | <i>Substance</i>                                                                               | <i>Method</i>                             |
|---------------------|------------------------------------------------------------------------------------------------|-------------------------------------------|
|                     | chromium                                                                                       | atomic absorption spectrometry            |
|                     | hydrocarbon oil index                                                                          | solvent extraction and gas chromatography |
|                     | halogenated hydrocarbons (volatile)                                                            | gas chromatography                        |
|                     | total organic carbon and dissolved organic carbon                                              |                                           |
|                     | organically bound halogen                                                                      |                                           |
|                     | alpha and beta activity                                                                        |                                           |
|                     | suspended solids                                                                               | filtration through glass fibre            |
|                     | electrical conductivity turbidity                                                              |                                           |
| BS EN 11732         | ammonium nitrogen                                                                              | flow analysis and spectrometry            |
| BS EN 12020         | aluminium                                                                                      | atomic absorption spectrometry            |
| BS EN 1483          | mercury                                                                                        |                                           |
| BS EN 1484          | total organic carbon and dissolved organic carbon                                              |                                           |
| BS EN 12338         | mercury                                                                                        | enrichment by amalgamation                |
| BS EN 14911         | dissolved sodium lithium ammonium, potassium, manganese, calcium, magnesium, strontium, barium |                                           |
| BS EN 25663         | nitrogen                                                                                       | ion chromatography                        |
| BS EN 26777         | nitrite                                                                                        | Kjeldahl                                  |
|                     |                                                                                                | molecular absorption spectrometry         |
| BS EN 7887          | colour                                                                                         |                                           |
| BS EN 1622          | odour                                                                                          |                                           |
| BS EN ISO 12020     | aluminium                                                                                      | atomic absorption spectrometry            |
| BS EN 13395         | nitrate and nitrite nitrogen                                                                   | flow analysis and spectrometry            |
| BS EN ISO 9377      | hydrocarbon oil index                                                                          | solvent extraction/gravimetry             |

Table 10.10 Common instrumental techniques for soil analysis

| <i>Pollutant</i>                            | <i>Method</i>                                           |
|---------------------------------------------|---------------------------------------------------------|
| Phosphorus or mineral nitrogen              | Spectrophotometry                                       |
| Alkaline earth metals and transition metals | Flame atomic absorption spectrometry                    |
| Alkali metals                               | Flame emission spectrometry                             |
| Aluminium, boron, silicon                   | Inductively coupled plasma atomic emission spectrometry |
| Lead in soil slurries                       | Electrothermal atomic absorption spectrometry           |
| Toxic organic compounds                     | High pressure liquid chromatography                     |

One of the most commonly used portable, gas detection systems is based on colour indicator tubes employed, in the main, for grab sampling. Tubes are available to detect over 300 substances (Table 10.18) and, using a combination of tubes, a range of concentrations can be measured. The technique relies on a manually-operated bellows or piston pump to aspirate a fixed volume of atmosphere through a glass tube containing crystals (e.g. silica gel or alumina) impregnated with a reagent which undergoes a colour change upon reaction with a specific pollutant or class of pollutant. The length of stain that develops is proportional to the concentration of contaminant and the tube is generally calibrated to permit direct read-off in parts per million. Sample lines of several metres between the pump and tube allow atmospheres to be sampled, e.g., inside vessels. A smaller number of special tubes (Table 10.18(b)) are available for longer-term monitoring and these

**Table 10.11 Selected British Standard methods for monitoring soil quality**

| <i>British Standard reference</i> | <i>Contaminant</i>                                                   | <i>Method</i>                                                                           |
|-----------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| BS 7755                           | dry matter                                                           | gravimetric                                                                             |
|                                   | pH                                                                   |                                                                                         |
|                                   | effective cation exchange capacity                                   | barium chloride reagent                                                                 |
|                                   | phosphorus                                                           | spectrometry                                                                            |
|                                   | total nitrogen                                                       | modified Kjeldahl analysis                                                              |
|                                   | organic and total carbon                                             | elementary analysis                                                                     |
|                                   | trace elements                                                       | extraction with aqua regia                                                              |
|                                   | carbonate content                                                    | volumetric                                                                              |
|                                   | water- and acid-soluble sulphate                                     | barium chloride reagent                                                                 |
|                                   | potential cation exchange capacity                                   |                                                                                         |
|                                   | cadmium, chromium, cobalt, copper, lead, manganese, nickel, and zinc | extraction with aqua regia with flame and electrothermal atomic absorption spectrometry |
|                                   | polynuclear aromatic hydrocarbons                                    | high performance liquid chromatography                                                  |
|                                   | redox potential                                                      | field method                                                                            |
| BS 8855                           | trace elements                                                       | extraction with DTPA or digestion with hydrofluoric and perchloric acids                |
|                                   | coal tar derived phenolic compounds                                  |                                                                                         |

are used in conjunction with battery-powered pumps operating at a flowrate of 10–20 ml/s. Again the average concentrations can be read off directly after an exposure period of, e.g., 8 hours. Direct-reading colorimetric diffusion tubes requiring no pump are available for a small number of substances (Table 10.18(c)). Because of their simplicity, colour indicator tubes are widely used but their limitations must be appreciated; sources of inaccuracy are given in Table 10.19.

Portable or fixed multi-point colorimetric detectors are available which rely on paper tape impregnated with the reagent. A cassette of the treated paper is driven electrically at constant speed over a sampling orifice and the stain intensity measured by an internal reflectometer to provide direct read out of concentration of contaminant in sample. Such instruments are available for a range of chemicals including the selection given in Table 10.20.

## Flammable gases

Flammable atmospheres can be assessed using portable gas chromatographs or, for selected compounds, by colour indicator tubes. More commonly, use is made of ‘explosimeters’ fitted with Pellistors (e.g. platinum wire encased in beads of refractory material). The beads are arranged in a Wheatstone bridge circuit. The flammable gas is oxidized on the heated catalytic element, causing the electrical resistance to alter relative to the reference. Instruments are calibrated for specific compounds in terms of 0–100% of their lower flammable limit. Recalibration or application of correction factors is required for different gases. These types of sensor are subject to ‘poisoning’ by certain chemicals such as silicone, sulphur, and halogen compounds. Points to consider are listed in Table 10.21.

Semiconductors resembling Pellistors are also available, e.g. a platinum/rhodium filament is used to heat a pellet of doped oxide which absorbs any flammable gas passing over it, causing the electrical conductivity to alter and subsequently the voltage in the electrodes attached to the pellet. Amplification of the signal registers a deflection on the meter. Again, errors can arise if the instrument is used for gases other than those for which it is calibrated. These sensors offer a long life expectancy; they are not restricted to flammable substances.

**Table 10.12 Selected examples of sampling techniques for air contaminants**

| <i>Contaminant</i>                                                                                              | <i>Principle</i>                                                                                   | <i>Apparatus</i>                                                                                                                                      | <i>Collecting agent</i>                  | <i>Sampling rate (l/min)</i>                              | <i>Collection efficiency (%)</i>                            | <i>Remarks</i>                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|-----------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Gases or vapours that are water soluble or miscible or that are only soluble or highly reactive in other agents | Absorption with simple washing                                                                     | Petri bottle<br>Wash bottle<br>Drechsel bottle<br>Impinger                                                                                            | Water, acid, alkali, or organic solvent  | 1–5                                                       | 90–100                                                      | Two units in series can be used for highly reactive gases in other reagents                                       |
| Gases or vapours of all types<br>Mists and fumes                                                                | Absorption with multiple contact washing by dispersing gas into fine bubbles of large surface area | Fritted or sintered glass, alundum, stainless steel, or plastics                                                                                      | Water, acid, alkali, or organic solvents | 1–15 (depends upon flask and sintered surface dimensions) | 95–100                                                      | May plug if large particulates are present or precipitates form from reactions<br>Fumes require very slow rates   |
| Gases or vapours of all types<br>Mists                                                                          | Absorption with multiple contact provided by wetted surfaces                                       | Packed columns of glass beads, glass spirals, or fibres<br>Plastic packing also feasible in some cases<br>Large surface wall area units also included | Water, acid, alkali, or organic solvents | 1–5                                                       | 90–100                                                      | May incorporate device for continually wetting column<br>High loadings of particulates may plug unit with packing |
| Gases or vapours that are water soluble or miscible or that are only soluble or highly reactive in other agents | Absorption with multiple surface contact by atomizing liquid with spray nozzle or jet impaction    | Crabtree ozone analyser or midget<br>venturi scrubber                                                                                                 | Water, acid, or alkali                   | 5–25                                                      | 60–100                                                      | Venturi scrubber satisfactory if dust is present<br>Atomizer absorber will plug                                   |
| Combustible gases or vapours that are not water soluble but are slowly reactive with absorbing agents           | Combustion and absorption                                                                          | Quartz or ceramic furnace with absorbers                                                                                                              | Water, acid, or alkali                   | 1–5                                                       | 90–100                                                      | Can also be used for organic halogenated fumes                                                                    |
| Gases or vapours that are not water soluble but are slowly reactive, with absorbing agent                       | Condensation                                                                                       | Freezing traps or low temperature condensers<br>Glass or metal                                                                                        | Dry                                      | 1–5                                                       | 90–100 (depends on vapour pressures at reduced temperature) | Can be packed with glass beads or other extended surfaces                                                         |

**Table 10.13 Common sorbent materials and applications**

| <i>Sorbent material</i>      | <i>Application</i>                                                                                                        |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Anasorb activated charcoal   | Solvent desorption. Polar organic compounds                                                                               |
| Anasorb graphitized charcoal | Various grades for collection of substances of a range of volatilities                                                    |
| Charcoal                     | Usually for solvent desorption especially of non-polar compounds                                                          |
| Chromasorb                   | Hydrocarbons, high molecular-weight organic vapours, chlorinated organic compounds                                        |
| Florisil                     | Halogenated hydrocarbons including PCBs                                                                                   |
| Hopcalite                    | Mercury vapour                                                                                                            |
| Molecular sieve              | Nitrogen oxides                                                                                                           |
| Polyurethane foam            | Halogenated compounds including PCBs, dioxins, furans and organophosphorus compounds                                      |
| Porous polymer               | Various types usually for solvent desorption; suitable for a range of organic compounds including highly polar substances |
| Silica gel                   | Aldehydes, amines, ammonia, chlorophenols, esters, inorganic acid gases, methanol, nitro compounds                        |
| Tenax                        | Various grades for collection of a range of boiling-point compounds. Suitable for low ambient concentrations              |

**Table 10.14 Thermal desorption of sorbed gas from sample tubes****Advantages over solvent extraction**

Elimination of sample preparation and handling of toxic solvents such as carbon disulphide

Absence of solvent simplifies chromatograph

Increased sensitivity

Sample tubes can be reused

Greater range of detection systems to which the desorbed gas can be subjected (e.g. chromatography, infra-red and ultraviolet spectroscopy, colorimetry)

**Limitations**

Certain resins undergo degradation even below 250 °C

Test sample may be thermally unstable

Not all compounds readily desorb

The entire test sample is used with no opportunity for repeat analyses

## Toxic particulates

Airborne particulates include dust, fume and aerosols. Many such particles are invisible to the naked eye under normal lighting but are rendered visible, by reflection, when illuminated with a strong beam of light. This is the 'Tyndall effect' and use of a dust lamp provides a simple technique for the rapid assessment of whether a dust is present, its flow pattern, leak sources, the effects of ventilation, etc. More sophisticated approaches are needed for quantitative data. Whether personal, spot or static sampling is adopted will depend upon the nature of the information required.

Air in the general atmosphere, or in the breathing zone of individuals, may be collected using a pump coupled to a means of isolating particulate matter for subsequent analysis or determination (Table 10.23). It is important to differentiate between 'total inhalable dust' i.e., the fraction of airborne material which enters the nose and mouth during breathing and is hence available for deposition in the respiratory tract, and 'respirable dust', i.e. the fraction which penetrates to the gas exchange region of the lung. For this purpose techniques for separating dust or aerosol



**Table 10.15 Charcoal tube user guide**

| Substance               | Expected concentration range <sup>(1)</sup> |                      | Recommended sampling <sup>(2)</sup><br>(ml/min) |      |      | Recommended maximum tube load <sup>(3)</sup><br>(mg) | Approximate desorption efficiency <sup>(4)</sup><br>(%) | Eluent <sup>(5)</sup> |
|-------------------------|---------------------------------------------|----------------------|-------------------------------------------------|------|------|------------------------------------------------------|---------------------------------------------------------|-----------------------|
|                         | (ppm)                                       | (mg/m <sup>3</sup> ) | 2 hr                                            | 4 hr | 8 hr |                                                      |                                                         |                       |
| Acetaldehyde            | 2–50                                        | 4–90                 | 100                                             | 100  | 50   |                                                      |                                                         |                       |
|                         | 50–400                                      | 90–720               | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Acetone                 | 5–200                                       | 12–480               | 100                                             | 50   | 25   | 9                                                    | 86 ± 10                                                 | CS <sub>2</sub>       |
|                         | 200–2000                                    | 480–4800             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Acetic acid             | 0.1–1                                       | 0.25–2.5             | –                                               | 200  | 200  | 10.4                                                 |                                                         | 11                    |
|                         | 1–20                                        | 2.5–50               | 200                                             | 100  | 50   |                                                      |                                                         |                       |
| Acetonitrile            | 1–10                                        | 1.8–17.5             | 100                                             | 100  | 50   | 2.7                                                  |                                                         |                       |
|                         | 10–80                                       | 17.5–140             | 50                                              | 25   |      |                                                      |                                                         |                       |
| Acrolein                | 0.02–0.2                                    | 0.05–0.5             | –                                               | –    | 200  |                                                      |                                                         |                       |
| Acrylonitrile           | 0.2–2                                       | 0.45–4.5             | 200                                             | 200  | 100  | >2                                                   | <80                                                     | 12                    |
|                         | 2–40                                        | 4.5–90               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Allyl alcohol           | 0.1–0.5                                     | 0.24–1.20            | –                                               | 200  | 200  | <0.4                                                 | 89 ± 5                                                  | 2                     |
|                         | 0.5–4                                       | 1.2–9.6              | 200                                             | 100  | 50   |                                                      |                                                         |                       |
| Allyl chloride          | 0.05–2                                      | 0.15–6               | –                                               | –    | 200  | 0.75                                                 |                                                         | 13                    |
| <i>n</i> -Amyl acetate  | 1–25                                        | 5.3–131.3            | 100                                             | 100  | 50   | 15                                                   | 86 ± 5                                                  | CS <sub>2</sub>       |
|                         | 25–200                                      | 131.3–1050           | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| sec-Amyl acetate        | 1–25                                        | 5.3–131.3            | 100                                             | 100  | 50   | 15.5                                                 | 91 ± 10                                                 | CS <sub>2</sub>       |
|                         | 25–250                                      | 131–1300             | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Isoamyl alcohol         | 1–25                                        | 3.6–90               | 100                                             | 100  | 50   | 10                                                   |                                                         |                       |
|                         | 25–200                                      | 90–720               | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Benzene                 | 0.1–1                                       | 0.31–3.1             | –                                               | 200  | 200  |                                                      | 96                                                      | CS <sub>2</sub>       |
|                         | 1–20                                        | 3.1–62.6             | 100                                             | 100  | 50   |                                                      |                                                         |                       |
| Benzyl chloride         | 0.05–2                                      | 0.25–10              | –                                               | 200  | 200  | >0.4                                                 | 90 ± 5                                                  | CS <sub>2</sub>       |
| Bromoform               | 0.05–1                                      | 0.5–10               | 200                                             | 100  | 50   | >0.25                                                |                                                         | CS <sub>2</sub>       |
| Butadiene               | 5–100                                       | 11–220               | 100                                             | 50   | 25   | 4                                                    |                                                         |                       |
|                         | 100–2000                                    | 220–4400             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| 2-Butoxyl ethanol       | 0.5–10                                      | 2.4–48               | 100                                             | 100  | 50   |                                                      | 95 ± 5                                                  | 6                     |
|                         | 10–100                                      | 48–480               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| <i>n</i> -butyl acetate | 1–25                                        | 4.7–118              | 100                                             | 100  | 50   | 15                                                   | 95                                                      | CS <sub>2</sub>       |
|                         | 25–300                                      | 118–1420             | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| sec-Butyl acetate       | 1–50                                        | 4.8–237.5            | 100                                             | 100  | 50   | 15                                                   | 91 ± 5                                                  | CS <sub>2</sub>       |
|                         | 50–400                                      | 237.5–1900           | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| tert-Butyl acetate      | 1–50                                        | 4.8–237.5            | 100                                             | 100  | 50   | 12.5                                                 | 94 ± 5                                                  | CS <sub>2</sub>       |
|                         | 50–400                                      | 237.5–1900           | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Butyl alcohol           | 1–25                                        | 3–75                 | 200                                             | 100  | 50   | 10.5                                                 | 88 ± 5                                                  | 3                     |
|                         | 25–200                                      | 75–600               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| sec-Butyl alcohol       | 1–30                                        | 3–90                 | 200                                             | 100  | 50   | 6                                                    | 93 ± 5                                                  | 3                     |
|                         | 30–300                                      | 90–900               | 50                                              | 25   | 10   |                                                      |                                                         |                       |

|                              |          |            |     |     |     |      |         |                 |
|------------------------------|----------|------------|-----|-----|-----|------|---------|-----------------|
| tert-Butyl alcohol           | 1–25     | 3–75       | 200 | 100 | 50  | 5    | 90 ± 5  | 3               |
|                              | 25–200   | 75–600     | 50  | 25  | 10  |      |         |                 |
| Butylamine                   | 0.1–1    | 0.3–3      | –   | 200 | 200 |      |         |                 |
|                              | 0.5–10   | 1.5–30     | 200 | 100 | 50  |      |         |                 |
| Butyl glycidyl ether         | 0.5–10   | 1.4–54     | 200 | 100 | 50  | 11.5 | 85 ± 10 | CS <sub>2</sub> |
|                              | 10–100   | 54–540     | 100 | 50  | 25  |      |         |                 |
| <i>p</i> -tert Butyl toluene | 0.1–1    | 0.6–6      | 200 | 200 | 100 | 2.5  | 100+    | CS <sub>2</sub> |
|                              | 1–20     | 6–120      | 100 | 50  | 25  |      |         |                 |
| Camphor                      | 0.05–0.5 | 0.63–6.3   | 200 | 200 | 100 | 13.4 | 98 ± 5  | 1               |
|                              | 0.1–4    | 1.3–25     | 200 | 100 | 50  |      |         |                 |
| Carbon disulphide            | 0.5–5    | 1.5–15     | 200 | 200 | 100 |      | 95      | 13              |
|                              | 5–40     | 15–120     | 200 | 100 | 50  |      |         |                 |
| Carbon tetrachloride         | 0.2–2    | 1.3–13     | 200 | 200 | 100 | 7.5  | 97 ± 5  | CS <sub>2</sub> |
|                              | 2–20     | 13–130     | 200 | 100 | 50  |      |         |                 |
| Chlorobenzene                | 0.75–10  | 3.5–23.3   | 100 | 100 | 50  | 15.5 | 90 ± 5  | CS <sub>2</sub> |
|                              | 10–150   | 23.3–700   | 50  | 25  | 10  |      |         |                 |
| Chlorobromomethane           | 2–20     | 10.5–105   | 100 | 50  | 25  | 9.3  | 94 ± 5  | CS <sub>2</sub> |
|                              | 20–400   | 105–2100   | 25  | 10  | 5   |      |         |                 |
| Chloroform                   | 0.5–10   | 2.4–48     | 200 | 100 | 50  | 11   | 96 ± 5  | CS <sub>2</sub> |
|                              | 10–100   | 48–480     | 100 | 50  | 25  |      |         |                 |
| 1-Chloro-1-Nitropropane      | 0.2–5    | 1–25       | 200 | 100 | 50  |      |         |                 |
|                              | 5–40     | 25–200     | 100 | 50  | 25  |      |         |                 |
| Chloroprene                  | 0.5–5    | 1.8–18     | 200 | 100 | 50  |      |         |                 |
|                              | 5–50     | 18–180     | 100 | 50  | 25  |      |         |                 |
| <i>o</i> -Chlorotoluene      | 1–10     | 5–50       | 100 | 50  | 25  |      |         | CS <sub>2</sub> |
|                              | 10–100   | 50–500     | 50  | 25  | 10  |      |         |                 |
| Cresol (all isomers)         | 0.1–1    | 0.44–4.4   | 200 | 200 | 100 | >2.0 |         |                 |
|                              | 1–10     | 4.4–44     | 100 | 100 | 50  |      |         |                 |
| Crotonaldehyde               | 0.1–1    | 0.3–3      | –   | 200 | 200 |      |         |                 |
|                              | 0.5–4    | 1.5–12     | 100 | 100 | 50  |      |         |                 |
| Cumene                       | 0.5–10   | 2.5–49     | 100 | 100 | 50  | 11   | 100+    | CS <sub>2</sub> |
|                              | 10–100   | 49–490     | 50  | 25  | 10  |      |         |                 |
| Cyclohexane                  | 3–50     | 10.5–175   | 100 | 50  | 25  | 6.3  | 100+    | CS <sub>2</sub> |
|                              | 50–600   | 175–2100   | 25  | 10  | 5   |      |         |                 |
| Cyclohexanol                 | 0.5–10   | 2–40       | 200 | 100 | 50  | 10   | 99 ± 5  | 2               |
|                              | 10–100   | 40–400     | 100 | 50  | 25  |      |         |                 |
| Cyclohexanone                | 0.5–10   | 2–40       | 200 | 100 | 50  | 13   | 78 ± 5  | CS <sub>2</sub> |
|                              | 10–100   | 40–400     | 100 | 50  | 25  |      |         |                 |
| Cyclohexene                  | 3–50     | 10.2–169.2 | 100 | 50  | 25  |      | 100+    | CS <sub>2</sub> |
|                              | 50–600   | 169.2–2030 | 25  | 10  | 5   |      |         |                 |
| Diacetone alcohol            | 0.5–10   | 1.4–48     | 200 | 100 | 50  | 12   | 77 ± 10 | 2               |
|                              | 10–100   | 48–480     | 100 | 50  | 24  |      |         |                 |
| <i>o</i> -Dichlorobenzene    | 0.5–10   | 3–60       | 200 | 100 | 50  | 15   | 85 ± 5  | CS <sub>2</sub> |
|                              | 10–100   | 60–600     | 50  | 25  | 10  |      |         |                 |
| <i>p</i> -Dichlorobenzene    | 1–25     | 6–150      | 100 | 100 | 50  |      | 85 ± 5  | CS <sub>2</sub> |
|                              | 25–150   | 150–900    | 50  | 25  | 10  |      |         |                 |

Table 10.15 Cont'd

| Substance                            | Expected concentration range <sup>(1)</sup> |                         | Recommended sampling <sup>(2)</sup><br>(ml/min) |            |           | Recommended maximum tube load <sup>(3)</sup><br>(mg) | Approximate desorption efficiency <sup>(4)</sup><br>(%) | Eluent <sup>(5)</sup> |
|--------------------------------------|---------------------------------------------|-------------------------|-------------------------------------------------|------------|-----------|------------------------------------------------------|---------------------------------------------------------|-----------------------|
|                                      | (ppm)                                       | (mg/m <sup>3</sup> )    | 2 hr                                            | 4 hr       | 8 hr      |                                                      |                                                         |                       |
| Dichlorodifluoromethane (Freon 12)   | 5–100<br>100–2000                           | 24.8–495<br>495–9900    | 100<br>10                                       | 50<br>5    | 25<br>1   |                                                      |                                                         |                       |
| 1,1-Dichloroethane                   | 1–15<br>15–200                              | 4–60<br>60–300          | 100<br>50                                       | 100<br>25  | 50<br>10  | 7.5                                                  | 100+                                                    | CS <sub>2</sub>       |
| 1,2-Dichloroethylene                 | 2–25<br>25–400                              | 7.9–99<br>99–1580       | 100<br>25                                       | 50<br>10   | 25<br>5   | 5.1                                                  | 100+                                                    | CS <sub>2</sub>       |
| 1,1-Dichloro-1-nitroethane           | 0.1–1.5<br>1.5–20                           | 0.6–9<br>9–120          | 200<br>100                                      | 200<br>50  | 100<br>25 | 9                                                    |                                                         | CS <sub>2</sub>       |
| Dichloroethyl ether                  | 0.5–5<br>5–30                               | 3–30<br>30–180          | 200<br>100                                      | 100<br>50  | 50<br>25  |                                                      |                                                         |                       |
| Dichloromonofluoromethane (Freon 21) | 5–100<br>100–2000                           | 21–420<br>420–8400      | 100<br>10                                       | 50<br>5    | 25<br>1   |                                                      |                                                         |                       |
| Dichlorotetrafluoroethane            | 5–100<br>100–2000                           | 35–700<br>7000–14 000   | 50<br>5                                         | 25<br>1    | 10<br>1   |                                                      |                                                         |                       |
| Difluorodibromomethane               | 1–15<br>15–200                              | 8.6–129<br>129–1720     | 100<br>25                                       | 50<br>10   | 25<br>5   | 15                                                   |                                                         | CS <sub>2</sub>       |
| Diisobutyl ketone                    | 0.5–7.5<br>7.5–100                          | 2.9–43.5<br>43.5–580    | 200<br>100                                      | 100<br>50  | 50<br>25  | 12.5                                                 |                                                         | CS <sub>2</sub>       |
| Dimethylaniline                      | 0.1–1<br>1–10                               | 0.5–5<br>5–50           | 200<br>100                                      | 200<br>50  | 100<br>25 | >1.1                                                 | >80                                                     | CS <sub>2</sub>       |
| Dimethylformamide                    | 0.5–4<br>2–20                               | 1.5–12<br>6–60          | 200<br>100                                      | 100<br>100 | 50<br>50  |                                                      |                                                         |                       |
| p-Dioxane                            | 1–15<br>15–200                              | 3.6–54<br>54–720        | 200<br>100                                      | 100<br>50  | 50<br>25  | 13                                                   | 91 ± 5                                                  | CS <sub>2</sub>       |
| Dipropylene glycol methyl ether      | 1–15<br>15–200                              | 6–90<br>90–1200         | 100<br>25                                       | 50<br>10   | 25<br>5   |                                                      | 75 ± 15                                                 | CS <sub>2</sub>       |
| Epichlorohydrin                      | 0.1–1<br>1–10                               | 0.4–4<br>4–40           | –<br>100                                        | 200<br>50  | 100<br>25 | >1                                                   | >80                                                     | CS <sub>2</sub>       |
| 2-Ethoxyethanol                      | 2–30<br>30–400                              | 7.4–111<br>111–1480     | 100<br>50                                       | 50<br>25   | 25<br>10  |                                                      |                                                         |                       |
| 2-Ethoxyethyl acetate                | 1–15<br>15–200                              | 5.4–81<br>81–1080       | 200<br>50                                       | 100<br>25  | 50<br>10  | 19                                                   | 74 ± 10                                                 | CS <sub>2</sub>       |
| Ethyl acetate                        | 5–75<br>75–800                              | 17.5–263<br>263–2800    | 100<br>25                                       | 50<br>10   | 25<br>5   | 12.5                                                 | 90 ± 10                                                 | CS <sub>2</sub>       |
| Ethyl acrylate                       | 0.5–5<br>5–50                               | 2–20<br>20–200          | 200<br>200                                      | 200<br>100 | 100<br>50 | <5                                                   | 95 ± 5                                                  | CS <sub>2</sub>       |
| Ethyl alcohol                        | 5–100<br>100–2000                           | 9.4–188.5<br>188.5–3770 | 100<br>5                                        | 50<br>1    | 25<br>1   | 2.6                                                  | 77 ± 10                                                 | 5                     |

|                                      |          |            |     |     |     |       |         |                 |
|--------------------------------------|----------|------------|-----|-----|-----|-------|---------|-----------------|
| Ethyl benzene                        | 1–15     | 4.4–65.3   | 200 | 100 | 50  | 16    | 100+    | CS <sub>2</sub> |
|                                      | 15–200   | 65.3–870   | 100 | 50  | 25  |       |         |                 |
| Ethyl bromide                        | 2–50     | 8.9–223    | 100 | 50  | 25  | 7.1   | 83 ± 5  | 4               |
|                                      | 50–400   | 223–1780   | 25  | 10  | 5   |       |         |                 |
| Ethyl butyl ketone                   | 0.5–10   | 2.3–46     | 200 | 100 | 50  | >5.5  | 93 ± 5  | 1               |
|                                      | 10–100   | 46–460     | 50  | 25  | 10  |       |         |                 |
| Ethyl chloride                       | 10–150   | 26–390     | 100 | 50  | 25  | 9.7   |         | CS <sub>2</sub> |
|                                      | 150–2000 | 390–5200   | 10  | 5   | 1   |       |         |                 |
| Ethyl ether                          | 5–75     | 15–227     | 100 | 50  | 25  | 7.5   | 98 ± 5  | 7               |
|                                      | 75–800   | 227–2420   | 10  | 5   | 1   |       |         |                 |
| Ethyl formate                        | 1–15     | 3–45       | 200 | 100 | 50  | 4.8   | 80 ± 10 | CS <sub>2</sub> |
|                                      | 15–200   | 45–600     | 50  | 25  | 10  |       |         |                 |
| Ethylene chlorohydrin <sup>(6)</sup> | 0.1–2    | 0.32–6.4   | –   | 200 | 200 | 16.0  | 92 ± 5  | 10              |
|                                      | 1–10     | 3.2–32     | 200 | 100 | 50  |       |         |                 |
| Ethylene dibromide                   | 0.2–5    | 1.6–38.88  | 200 | 200 | 100 | >10.7 | 93 ± 5  | CS <sub>2</sub> |
|                                      | 2–40     | 15.5–310   | 100 | 50  | 25  |       |         |                 |
| Ethylene dichloride                  | 0.5–10   | 2–40.5     | 200 | 200 | 100 | 12    | 95 ± 5  | CS <sub>2</sub> |
|                                      | 10–100   | 40.5–405   | 100 | 50  | 25  |       |         |                 |
| Ethylene oxide                       | 0.5–10   | 0.9–18     | 200 | 100 | 50  | 1.1   |         | CS <sub>2</sub> |
|                                      | 10–100   | 18–180     | 100 | 50  | 25  |       |         |                 |
| Fluorotrichloromethane<br>(Freon 11) | 5–100    | 28–560     | 100 | 50  | 25  |       |         |                 |
|                                      | 100–2000 | 560–11 200 | 5   | 1   | 1   |       |         |                 |
| Furfural                             | 0.1–2    | 0.4–8      | 200 | 200 | 100 |       | >80     | CS <sub>2</sub> |
|                                      | 1–10     | 4–40       | 200 | 100 | 50  |       |         |                 |
| Furfuryl alcohol                     | 0.5–20   | 2–80       | 200 | 100 | 50  |       |         |                 |
|                                      | 10–100   | 40–400     | 50  | 25  | 10  |       |         |                 |
| Glycidol                             | 0.5–20   | 1.5–60     | 200 | 100 | 50  | 22.5  | 90 ± 5  | 8               |
|                                      | 10–100   | 30–300     | 100 | 50  | 25  |       |         |                 |
| Heptane                              | 5–100    | 20–400     | 100 | 50  | 25  | 12.5  | 96 ± 5  | CS <sub>2</sub> |
|                                      | 100–1000 | 400–4000   | 10  | 5   | 1   |       |         |                 |
| Hexachloroethane                     | 0.05–2   | 0.5–20     | 200 | 200 | 100 |       | 98 ± 5  | CS <sub>2</sub> |
| Hexane                               | 5–100    | 18–360     | 100 | 50  | 25  | 11    | 94 ± 5  | CS <sub>2</sub> |
|                                      | 100–1000 | 360–3600   | 10  | 5   | 1   |       |         |                 |
| Isoamyl acetate                      | 1–15     | 5.3–78.8   | 200 | 100 | 50  | 16.5  | 90 ± 5  | CS <sub>2</sub> |
|                                      | 15–200   | 78.8–1050  | 50  | 25  | 10  |       |         |                 |
| Isoamyl alcohol                      | 1–15     | 3.6–54     | 200 | 100 | 50  | 10    | 99 ± 5  | 2               |
|                                      | 15–200   | 54–720     | 50  | 25  | 10  |       |         |                 |
| Isobutyl acetate                     | 1–20     | 4.7–93     | 200 | 100 | 50  | 14    | 92 ± 5  | CS <sub>2</sub> |
|                                      | 20–300   | 93–1400    | 50  | 25  | 10  |       |         |                 |
| Isobutyl alcohol                     | 1–15     | 3–46       | 200 | 100 | 50  | 10.5  | 84 ± 10 | 3               |
|                                      | 15–200   | 46–610     | 50  | 25  | 10  |       |         |                 |
| Isophorone                           | 0.5–5    | 2.8–28     | 200 | 100 | 50  | 13    | >80     | CS <sub>2</sub> |
|                                      | 5–50     | 28–280     | 50  | 25  | 10  |       |         |                 |
| Isopropyl acetate                    | 2–50     | 7.6–190    | 100 | 100 | 50  | 13    | 85 ± 5  | CS <sub>2</sub> |
|                                      | 50–500   | 190–1900   | 25  | 10  | 5   |       |         |                 |

Table 10.15 Cont'd

| Substance                                 | Expected concentration range <sup>(1)</sup>                 |                      | Recommended sampling <sup>(2)</sup><br>(ml/min) |      |      | Recommended maximum tube load <sup>(3)</sup><br>(mg) | Approximate desorption efficiency <sup>(4)</sup><br>(%) | Eluent <sup>(5)</sup> |
|-------------------------------------------|-------------------------------------------------------------|----------------------|-------------------------------------------------|------|------|------------------------------------------------------|---------------------------------------------------------|-----------------------|
|                                           | (ppm)                                                       | (mg/m <sup>3</sup> ) | 2 hr                                            | 4 hr | 8 hr |                                                      |                                                         |                       |
| Isopropyl alcohol                         | 5–75                                                        | 12.3–185             | 100                                             | 50   | 25   | 5.6                                                  | 94 ± 5                                                  | 5                     |
|                                           | 75–800                                                      | 185–1970             | 25                                              | 10   | 5    |                                                      |                                                         |                       |
| Isopropyl ether                           | 5–100                                                       | 21–420               | 100                                             | 50   | 25   | 10.5                                                 | 80 ± 10                                                 | CS <sub>2</sub>       |
|                                           | 100–1000                                                    | 420–4200             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Isopropyl glycidyl ether                  | 0.5–10                                                      | 2.4–48               | 200                                             | 100  | 50   |                                                      |                                                         |                       |
|                                           | 10–100                                                      | 48–480               | 100                                             | 50   | 25   | 4.8                                                  | 79 ± 5                                                  | 1                     |
| Mesityl oxide                             | 0.5–10                                                      | 2–40                 | 200                                             | 200  | 100  |                                                      |                                                         |                       |
|                                           | 5–50                                                        | 20–200               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Methyl acetate                            | 1–50                                                        | 3.1–152.5            | 200                                             | 100  | 50   | 7                                                    | 88 ± 5                                                  | CS <sub>2</sub>       |
|                                           | 50–400                                                      | 152.5–1220           | 25                                              | 10   | 5    |                                                      |                                                         |                       |
| Methyl acrylate                           | 0.1–2                                                       | 0.35–7               | –                                               | 200  | 100  | >1.5                                                 | 80 ± 10                                                 | CS <sub>2</sub>       |
|                                           | 1–20                                                        | 3.5–70               | 200                                             | 100  | 50   |                                                      |                                                         |                       |
| Methyl alcohol                            | Charcoal tube method not recommended. Use silica gel tubes. |                      |                                                 |      |      |                                                      |                                                         |                       |
| Methylal (dimethoxymethane)               | 5–100                                                       | 15.5–311             | 100                                             | 50   | 25   | 11.5                                                 | 78 ± 10                                                 | 9                     |
|                                           | 100–2000                                                    | 311–6220             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Methyl amyl ketone                        | 1–15                                                        | 4.7–70               | 200                                             | 100  | 50   | 7.5                                                  | 80 ± 10                                                 | 1                     |
|                                           | 15–200                                                      | 70–930               | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Methyl bromide                            | 0.5–4                                                       | 2–16                 | 200                                             | 100  | 50   | 1.5                                                  |                                                         | CS <sub>2</sub>       |
|                                           | 4–40                                                        | 16–160               | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Methyl butyl ketone (2-hexanone)          | 1–15                                                        | 4.1–61.5             | 200                                             | 100  | 50   | 2.0                                                  | 79 ± 10                                                 | CS <sub>2</sub>       |
|                                           | 15–200                                                      | 61.5–820             | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Methyl isobutyl ketone (hexanone)         | 1–15                                                        | 4.1–61.4             | 200                                             | 100  | 50   | 10                                                   | 81 ± 5                                                  | CS <sub>2</sub>       |
|                                           | 15–200                                                      | 61.4–818             | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Methyl cellosolve                         | 0.3–10                                                      | 1–32                 | 200                                             | 200  | 100  | 10                                                   | 97 ± 5                                                  | 6                     |
|                                           | 5–50                                                        | 16–160               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Methyl cellosolve acetate                 | 0.3–10                                                      | 1.5–48               | 200                                             | 100  | 50   | 5                                                    | 76 ± 10                                                 | CS <sub>2</sub>       |
|                                           | 5–50                                                        | 24–240               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Methyl chloride                           | 1–15                                                        | 2.1–31.5             | 200                                             | 100  | 50   | 1                                                    |                                                         | CS <sub>2</sub>       |
|                                           | 15–200                                                      | 31.5–420             | 25                                              | 10   | 5    |                                                      |                                                         |                       |
| Methyl chloroform (1,1,1 trichloroethane) | 1–75                                                        | 5.4–407              | 200                                             | 100  | 50   | 18                                                   | 98+                                                     | CS <sub>2</sub>       |
|                                           | 75–700                                                      | 407–3800             | 25                                              | 10   | 5    |                                                      |                                                         |                       |
| Methyl cyclohexane                        | 5–100                                                       | 20–400               | 100                                             | 50   | 25   | 9.5                                                  | 89 ± 10                                                 | CS <sub>2</sub>       |
|                                           | 100–1000                                                    | 400–4000             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Methyl ethyl ketone (2-butanone)          | 2–50                                                        | 5.9–148              | 100                                             | 100  | 50   |                                                      |                                                         |                       |
|                                           | 50–400                                                      | 148–1180             | 50                                              | 25   | 10   | >5                                                   |                                                         | 1                     |
| Methyl formate                            | 1–15                                                        | 2.5–37.5             | 200                                             | 100  | 50   |                                                      |                                                         |                       |
|                                           | 15–200                                                      | 37.5–500             | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| 5-Methyl-3-heptanone                      | 0.25–5                                                      | 1.3–26               | 200                                             | 100  | 50   | >5                                                   |                                                         | 1                     |
|                                           | 5–50                                                        | 26–260               | 100                                             | 50   | 25   |                                                      |                                                         |                       |

|                          |          |            |     |     |     |      |         |                 |
|--------------------------|----------|------------|-----|-----|-----|------|---------|-----------------|
| Methyl iodide            | 0.1–1    | 0.56–5.6   | 200 | 200 | 100 | 7    |         | 14              |
|                          | 1–10     | 5.6–56     | 100 | 50  | 25  |      |         |                 |
| Methyl isobutyl carbinol | 0.5–5    | 2.1–21     | 200 | 100 | 50  | 5.7  | 99 ± 5  | 2               |
|                          | 5–50     | 21–210     | 200 | 100 | 50  |      |         |                 |
| Methyl isoamylacetate    | 1–10     | 6–60       | 200 | 100 | 50  | 14   |         | CS <sub>2</sub> |
|                          | 10–100   | 60–600     | 100 | 50  | 25  |      |         |                 |
| α-methyl styrene         | 1–15     | 4.8–72     | 200 | 200 | 100 | 21   | 91 ± 5  | CS <sub>2</sub> |
|                          | 15–200   | 72–960     | 100 | 50  | 25  |      |         |                 |
| Methylene chloride       | 5–75     | 17.4–261   | 100 | 100 | 50  | 9.3  | 95 ± 10 | CS <sub>2</sub> |
|                          | 75–1000  | 261–3480   | 10  | 5   | 1   |      |         |                 |
| Naphtha (coal tar)       | 1–15     | 4–60       | 200 | 100 | 50  | 14.8 | 88 ± 5  | CS <sub>2</sub> |
|                          | 15–200   | 60–800     | 100 | 50  | 25  |      |         |                 |
| Naphthalene              | 0.1–2    | 0.5–10     | 200 | 200 | 100 |      |         |                 |
|                          | 1–20     | 5–100      | 100 | 50  | 25  |      |         |                 |
| Nitromethane             | 1–15     | 3.1–46.5   | 200 | 200 | 100 |      |         |                 |
|                          | 15–200   | 46.5–620   | 50  | 25  | 10  |      |         |                 |
| 1-Nitropropane           | 0.5–10   | 1.8–36     | 200 | 100 | 50  |      |         |                 |
|                          | 5–50     | 18–180     | 100 | 50  | 25  |      |         |                 |
| 2-Nitropropane           | 0.5–10   | 1.8–36     | 200 | 100 | 50  |      |         |                 |
|                          | 5–50     | 18–180     | 100 | 50  | 25  |      |         |                 |
| Nonane                   | 2–30     | 10.5–157.5 | 100 | 50  | 25  |      |         | CS <sub>2</sub> |
|                          | 30–400   | 157.5–2100 | 25  | 10  | 5   |      |         |                 |
| n-Octane                 | 5–75     | 23.5–352   | 100 | 50  | 25  | 15   | 93 ± 5  | CS <sub>2</sub> |
|                          | 75–1000  | 352–4700   | 10  | 5   | 1   |      |         |                 |
| Pentane                  | 5–100    | 15–295     | 200 | 100 | 50  | 9    | 96 ± 5  | CS <sub>2</sub> |
|                          | 100–2000 | 295–5900   | 10  | 5   | 1   |      |         |                 |
| 2-Pentanone              | 1–75     | 3.5–263    | 200 | 100 | 50  |      | 88 ± 5  | CS <sub>2</sub> |
|                          | 75–400   | 263–1400   | 25  | 10  | 5   |      |         |                 |
| Perchloroethylene        | 1–15     | 6.8–102    | 200 | 100 | 50  | 29   | 95 ± 5  | CS <sub>2</sub> |
| (tetrachloroethylene)    | 15–200   | 102–1362   | 50  | 25  | 10  |      |         |                 |
| Petroleum distillates    | 5–75     | 20–300     | 100 | 50  | 25  | 12.3 | 96 ± 5  | CS <sub>2</sub> |
|                          | 75–1000  | 300–4000   | 10  | 5   | 1   |      |         |                 |
| Phenol                   | 0.1–2    | 0.38–7.6   | –   | 200 | 100 |      |         |                 |
|                          | 1–10     | 3.8–38     | 200 | 100 | 50  |      |         |                 |
| Phenyl ether (vapour)    | 0.05–2   | 0.35–14    | –   | 200 | 200 | 0.6  | 90 ± 5  | CS <sub>2</sub> |
| Phenyl glycidyl ether    | 0.5–4    | 3–24       | 200 | 100 | 50  | 12.5 | 97 ± 5  | CS <sub>2</sub> |
|                          | 2–20     | 12–120     | 100 | 50  | 25  |      |         |                 |
| n-Propyl acetate         | 1–75     | 4.2–315    | 200 | 100 | 50  | 14.5 | 93 ± 5  | CS <sub>2</sub> |
|                          | 75–400   | 315–1680   | 50  | 25  | 10  |      |         |                 |
| n-Propyl alcohol         | 1–75     | 2.5–184    | 200 | 100 | 50  | 9    | 87 ± 5  | 3               |
|                          | 75–400   | 184–980    | 50  | 25  | 10  |      |         |                 |
| Propylene dichloride     | 1–15     | 4.6–70     | 200 | 100 | 50  | 5    | 97 ± 5  | CS <sub>2</sub> |
|                          | 15–150   | 70–700     | 50  | 25  | 10  |      |         |                 |
| Propylene oxide          | 1–15     | 2.4–36     | 200 | 100 | 50  | 2    | 90 ± 5  | CS <sub>2</sub> |
|                          | 15–200   | 36–480     | 25  | 10  | 5   |      |         |                 |

Table 10.15 Cont'd

| Substance                                         | Expected concentration range <sup>(1)</sup> |                      | Recommended sampling <sup>(2)</sup><br>(ml/min) |      |      | Recommended maximum tube load <sup>(3)</sup><br>(mg) | Approximate desorption efficiency <sup>(4)</sup><br>(%) | Eluent <sup>(5)</sup> |
|---------------------------------------------------|---------------------------------------------|----------------------|-------------------------------------------------|------|------|------------------------------------------------------|---------------------------------------------------------|-----------------------|
|                                                   | (ppm)                                       | (mg/m <sup>3</sup> ) | 2 hr                                            | 4 hr | 8 hr |                                                      |                                                         |                       |
| <i>n</i> -Propyl nitrate                          | 0.5–5                                       | 2.2–22               | 200                                             | 100  | 50   | 12                                                   |                                                         | CS <sub>2</sub>       |
|                                                   | 5–50                                        | 22–220               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Pyridine                                          | 0.5–2                                       | 1.5–6                | 200                                             | 200  | 100  | >7.3                                                 | 70 ± 10                                                 | CS <sub>2</sub>       |
|                                                   | 1–10                                        | 3–30                 | 200                                             | 100  | 50   |                                                      |                                                         |                       |
| Stoddard solvent                                  | 5–75                                        | 29.5–443             | 100                                             | 50   | 25   | 13                                                   | 96 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 75–1000                                     | 443–5900             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Styrene (monomer)                                 | 1–15                                        | 4.3–64               | 200                                             | 100  | 50   | 18                                                   | 87 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 75–1000                                     | 64–850               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| 1,1,1,2-Tetrachloro-2,2-Difluoroethane            | 5–75                                        | 42–625               | 100                                             | 50   | 25   | 19.5                                                 | 100+ CS <sub>2</sub>                                    |                       |
|                                                   | 75–1000                                     | 625–8340             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| 1,1,2,2-Tetrachloro-1,2-Difluoroethane            | 5–75                                        | 42–625               | 100                                             | 50   | 25   | 26                                                   | 96 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 75–1000                                     | 625–8340             | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| 1,1,2,2-Tetrachloroethane <sup>(6)</sup>          | 0.1–2                                       | 0.7–14               | 200                                             | 200  | 100  | 4.5                                                  | 85 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 1–10                                        | 7–70                 | 100                                             | 100  | 50   |                                                      |                                                         |                       |
| Tetrahydrofuran                                   | 1–75                                        | 2.5–184              | 200                                             | 100  | 50   | 7.5                                                  | 92 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 75–400                                      | 184–1180             | 25                                              | 10   | 5    |                                                      |                                                         |                       |
| Tetramethyl succinonitrile                        | 0.05–1                                      | 0.3–6                | –                                               | 200  | 200  | >0.8                                                 |                                                         | CS <sub>2</sub>       |
| Toluene                                           | 1–15                                        | 3.8–56               | 200                                             | 100  | 50   |                                                      | 92 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 15–200                                      | 56–750               | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| 1,1,2-trichloroethane                             | 0.1–2                                       | 0.6–11               | 200                                             | 100  | 50   | 5                                                    | 96 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 2–20                                        | 11–110               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Trichloroethylene                                 | 1–15                                        | 5.4–80               | 200                                             | 100  | 50   | 21                                                   | 96 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 15–200                                      | 80–1070              | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| 1,2,3-Trichloropropane                            | 0.5–10                                      | 3–60                 | 200                                             | 100  | 50   | 14                                                   |                                                         | CS <sub>2</sub>       |
|                                                   | 10–100                                      | 60–600               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| 1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113) | 10–150                                      | 77–1150              | 100                                             | 50   | 25   | 20                                                   | 100+                                                    | CS <sub>2</sub>       |
|                                                   | 150–2000                                    | 1150–15 300          | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Trifluoromonobromomethane <sup>(7)</sup>          | 10–150                                      | 61–914               | 100                                             | 50   | 25   | 25                                                   |                                                         |                       |
|                                                   | 150–2000                                    | 914–12 180           | 10                                              | 5    | 1    |                                                      |                                                         |                       |
| Turpentine                                        | 1–15                                        | 5.6–84               | 200                                             | 100  | 50   | 13                                                   | 96 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 15–200                                      | 84–1120              | 50                                              | 25   | 10   |                                                      |                                                         |                       |
| Vinyl chloride <sup>(7)</sup>                     | 0.05–1                                      | 0.13–2.5             | –                                               | –    | 200  |                                                      | 85 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 0.5–2                                       | 1.3–5.2              | 200                                             | 200  | 100  |                                                      |                                                         |                       |
| Vinyl toluene                                     | 1–15                                        | 4.8–72               | 200                                             | 100  | 50   | 17                                                   | 85 ± 10                                                 | CS <sub>2</sub>       |
|                                                   | 15–200                                      | 72–960               | 100                                             | 50   | 25   |                                                      |                                                         |                       |
| Xylene                                            | 1–15                                        | 4.4–65               | 200                                             | 100  | 50   |                                                      | 95 ± 5                                                  | CS <sub>2</sub>       |
|                                                   | 15–200                                      | 65–870               | 50                                              | 25   | 10   |                                                      |                                                         |                       |

- (1) Two concentration ranges are given for most substances. The low range is approximately 1%–15% of the TLV and the high range 15%–200% TLV. The user should select from these two ranges the expected mean concentration.
- (2) A sampling rate is recommended for each concentration range and for a 2 hr, 4 hr, or 8 hr sampling period. Each sampling rate is given in ml/min and has been calculated to provide a minimum tube loading of at least 0.01 mg at the minimum concentration shown and not to exceed the recommended tube loading at the highest concentration shown for that range. These figures are based on the use of 100 mg coconut-shell charcoal tubes to the NIOSH recommended design except where otherwise noted.
- (3) A recovery of 5% of the total sample from the back-up section of charcoal in a sample tube was defined as the breakthrough point: 50% of this value is shown as the recommended maximum tube loading, to allow for high humidity or the presence of other substances which reduce the normal tube capacity.
- (4) The figures given are not intended to be used as exact desorption efficiencies and are only given as a guide when carrying out system calibrations. Actual desorption efficiencies should always be determined at the time of analysis. However, these figures represent the best obtainable data from several sources, and any significant deviation should be regarded as a possible indication of a systematic error in the analytical technique. The figure given for desorption efficiency is an average figure. The desorption efficiency for a compound will vary with the amount of substance on the tube. With reduced tube loadings, in most cases, the desorption efficiency will be lower. Significant errors may be introduced when analysing small amounts of substance and an average desorption efficiency factor is used.
- (5) The desorption efficiencies given are directly related to the eluent used. All data in the desorption efficiency column correspond to the specific eluent listed:
 

|                                    |                                         |
|------------------------------------|-----------------------------------------|
| 1 CS <sub>2</sub> + 1% methanol    | 8 Tetrahydrofuran 0.5 ml                |
| 2 CS <sub>2</sub> + 5% 2-propanol  | 9 Hexane 0.5 ml                         |
| 3 CS <sub>2</sub> + 1% 2-propanol  | 10 CS <sub>2</sub> + 5% isoamyl alcohol |
| 4 Isopropanol                      | 11 Formic acid                          |
| 5 CS <sub>2</sub> + 1% butanol     | 12 Methanol                             |
| 6 Methylene chloride + 5% methanol | 13 Benzene                              |
| 7 Ethyl acetate 0.5 ml             | 14 Toluene                              |
- (6) 100 mg petroleum-based charcoal tubes based on the NIOSH recommended design should be used for sample collection of these compounds.
- (7) These compounds migrate rapidly to the back-up section of the charcoal tube. A 400 mg tube should be used for sample collection with a second 100 mg tube in series behind the large tube to determine breakthrough.



Table 10.16 Chromatographic column guide for Century organic vapour analyser

| Compound                                                     | Relative response <sup>(1)</sup> (%) | Column temperature <sup>(2)</sup> (°C) | Column packing retention time (min:secs) |       |       |
|--------------------------------------------------------------|--------------------------------------|----------------------------------------|------------------------------------------|-------|-------|
|                                                              |                                      |                                        | B-8                                      | G-8   | T-8   |
| Acetone                                                      | 60                                   | 0                                      | 0:37                                     | 0:27  | 1:50  |
|                                                              |                                      | 40                                     | 0:20                                     | 0:15  | 0:30  |
| Acetonitrile                                                 | 70                                   | 0                                      | 0:40                                     | 0:30  | 5:24  |
|                                                              |                                      | 40                                     | 0:20                                     | 0:18  | 1:15  |
| Acrylonitrile                                                | 70                                   | 0                                      | 0:35                                     | 0:30  | 3:45  |
|                                                              |                                      | 40                                     | 0:19                                     | 0:17  | 0:51  |
| Allyl alcohol                                                | 30                                   | 0                                      | 1:15                                     | 0:44  | 11:45 |
|                                                              |                                      | 40                                     | 0:37                                     | 0:26  | 1:35  |
| Allyl chloride                                               | 50                                   | 0                                      | 0:16                                     | 0:28  | 0:31  |
|                                                              |                                      | 40                                     | 0:08                                     | 0:16  | 0:15  |
| Benzene                                                      | 150                                  | 0                                      | 0:50                                     | 1:19  | 1:43  |
|                                                              |                                      | 40                                     | 0:22                                     | 0:25  | 0:32  |
| 2-Bromo-2-chloro-1,1,1-trifluoroethane (Halothane)           | 45                                   | 0                                      | 0:37                                     | 0:35  | 0:58  |
|                                                              |                                      | 40                                     | 0:17                                     | 0:14  | 0:19  |
| Bromoethane                                                  | 75                                   | 0                                      | 0:15                                     | 0:26  | 0:23  |
|                                                              |                                      | 40                                     | 0:05                                     | 0:15  | 0:14  |
| 1-Bromopropane                                               | 75                                   | 0                                      | 0:21                                     | 0:58  | 0:40  |
|                                                              |                                      | 40                                     | 0:08                                     | 0:22  | 0:18  |
| 2-Butane                                                     | 60                                   | 0                                      | 0:15                                     | 0:15  | 0:10  |
|                                                              |                                      | 40                                     | —                                        | —     | —     |
| n-Butanol                                                    | 50                                   | 0                                      | 4:10                                     | 2:20  | 15:07 |
|                                                              |                                      | 40                                     | 0:24                                     | 0:53  | 1:44  |
| 2-Butanol                                                    | 65                                   | 0                                      | 1:45                                     | 0:55  | 6:07  |
|                                                              |                                      | 40                                     | 0:24                                     | 0:24  | 0:53  |
| n-Butyl acetate                                              | 80                                   | 0                                      | 4:15                                     | 7:30  | 11:40 |
|                                                              |                                      | 40                                     | 0:50                                     | 1:14  | 1:31  |
| n-Butyl acrylate                                             | 60                                   | 0                                      | —                                        | —     | —     |
|                                                              |                                      | 40                                     | 2:30                                     | 2:15  | 2:40  |
| 2-Butyl acrylate                                             | 70                                   | 0                                      | —                                        | —     | —     |
|                                                              |                                      | 40                                     | 1:22                                     | 1:45  | 1:46  |
| n-Butyl formate                                              | 50                                   | 0                                      | 2:15                                     | 2:57  | 4:40  |
|                                                              |                                      | 40                                     | 0:28                                     | 0:34  | 0:49  |
| 2-Butyl formate                                              | 60                                   | 0                                      | 1:22                                     | 2:00  | 3:31  |
|                                                              |                                      | 40                                     | 0:20                                     | 0:26  | 0:37  |
| n-Butyl methacrylate                                         | 60                                   | 0                                      | —                                        | —     | —     |
|                                                              |                                      | 40                                     | 4:03                                     | 5:46  | 5:10  |
| 2-Butyl methacrylate                                         | 80                                   | 0                                      | —                                        | —     | —     |
|                                                              |                                      | 40                                     | 2:46                                     | 3:40  | 3:34  |
| Carbon tetrachloride                                         | 10                                   | 0                                      | 0:20                                     | 1:24  | 0:37  |
|                                                              |                                      | 40                                     | 0:10                                     | 0:25  | 0:17  |
| Chlorobenzene                                                | 200                                  | 0                                      | 5:45                                     | 8:00  | 11:20 |
|                                                              |                                      | 40                                     | 1:08                                     | 1:24  | 1:35  |
| Chlorodifluoromethane (Freon 22)                             | 40                                   | 0                                      | 0:11                                     | 0:11  | 0:15  |
|                                                              |                                      | 40                                     | —                                        | —     | —     |
| Chloroform                                                   | 65                                   | 0                                      | 0:55                                     | 0:57  | 2:00  |
|                                                              |                                      | 40                                     | 0:20                                     | 0:20  | 0:31  |
| 1-Chloropropane                                              | 75                                   | 0                                      | 0:16                                     | 0:31  | 0:23  |
|                                                              |                                      | 40                                     | 0:05                                     | 0:16  | 0:14  |
| 2-Chloropropane                                              | 90                                   | 0                                      | 0:15                                     | 0:23  | 0:18  |
|                                                              |                                      | 40                                     | 0:05                                     | 0:05  | 0:05  |
| 2-Chloro-1,1,2-trifluoroethyl difluoromethyl ether (Ethrane) | 150                                  | 0                                      | 0:36                                     | 0:26  | 1:22  |
|                                                              |                                      | 40                                     | 0:13                                     | 0:12  | 0:19  |
| Cumene                                                       | 100                                  | 0                                      | 11:00                                    | 20:00 | 12:45 |
|                                                              |                                      | 40                                     | 2:20                                     | 3:03  | 2:19  |

Table 10.16 Cont'd

| Compound                                            | Relative response <sup>(1)</sup> (%) | Column temperature <sup>(2)</sup> (°C) | Column packing retention time (min:secs) |       |       |
|-----------------------------------------------------|--------------------------------------|----------------------------------------|------------------------------------------|-------|-------|
|                                                     |                                      |                                        | B-8                                      | G-8   | T-8   |
| Cyclohexane                                         | 85                                   | 0                                      | 0:36                                     | 1:25  | 0:19  |
|                                                     |                                      | 40                                     | 0:18                                     | 0:26  | 0:14  |
| Cyclohexanone                                       | 100                                  | 0                                      | 18:00                                    | 12:45 | —     |
|                                                     |                                      | 40                                     | 3:00                                     | 2:00  | —     |
| <i>n</i> -Decane                                    | 75                                   | 0                                      | —                                        | —     | —     |
|                                                     |                                      | 40                                     | 2:57                                     | 6:20  | 1:35  |
| <i>o</i> -Dichlorobenzene                           | 50                                   | 0                                      | —                                        | —     | —     |
|                                                     |                                      | 40                                     | 8:06                                     | 10:00 | 11:20 |
| Dichlorodifluoromethane (Freon 12)                  | 15                                   | 0                                      | 0:10                                     | 0:11  | 0:12  |
|                                                     |                                      | 40                                     | —                                        | —     | —     |
| 1,1-Dichloroethane                                  | 80                                   | 0                                      | 0:17                                     | 0:37  | 0:45  |
|                                                     |                                      | 40                                     | 0:08                                     | 0:17  | 0:18  |
| 1,2-Dichloroethane                                  | 80                                   | 0                                      | 1:14                                     | 1:08  | 3:50  |
|                                                     |                                      | 40                                     | 0:23                                     | 0:22  | 0:43  |
| <i>trans</i> 1,2-Dichloroethylene                   | 50                                   | 0                                      | 0:16                                     | 0:35  | 0:31  |
|                                                     |                                      | 40                                     | 0:05                                     | 0:18  | 0:16  |
| Dichlorofluoromethane (Freon 21)                    | 70                                   | 0                                      | 0:16                                     | 0:15  | 0:23  |
|                                                     |                                      | 40                                     | —                                        | —     | —     |
| Dichloromethane                                     | 100                                  | 0                                      | 0:27                                     | 0:29  | 1:08  |
|                                                     |                                      | 40                                     | 0:10                                     | 0:10  | 0:22  |
| 1,2-Dichloropropane                                 | 90                                   | 0                                      | 0:41                                     | 1:49  | 2:56  |
|                                                     |                                      | 40                                     | 0:18                                     | 0:29  | 0:36  |
| 1,3-Dichloropropane                                 | 80                                   | 0                                      | 1:32                                     | 4:12  | 4:24  |
|                                                     |                                      | 40                                     | 0:26                                     | 0:47  | 1:20  |
| 1,2-Dichloro 1,1,2,2,-tetrafluoroethane (Freon 114) | 110                                  | 0                                      | 0:12                                     | 0:12  | 0:14  |
|                                                     |                                      | 40                                     | —                                        | —     | —     |
| Diethyl ether                                       | 50                                   | 0                                      | 0:20                                     | 0:26  | 0:19  |
|                                                     |                                      | 40                                     | 0:05                                     | 0:05  | 0:05  |
| Diethyl ketone                                      | 80                                   | 0                                      | 2:00                                     | 2:01  | 3:16  |
|                                                     |                                      | 40                                     | 0:29                                     | 0:30  | 0:49  |
| <i>p</i> -Dioxane                                   | 30                                   | 0                                      | 3:15                                     | 2:09  | 6:40  |
|                                                     |                                      | 40                                     | 0:44                                     | 0:34  | 1:19  |
| Ethane                                              | 80                                   | 0                                      | 0:15                                     | 0:15  | 0:15  |
|                                                     |                                      | 40                                     | —                                        | —     | —     |
| Ethanethiol                                         | 30                                   | 0                                      | 0:18                                     | 0:24  | 0:26  |
|                                                     |                                      | 40                                     | 0:13                                     | 0:12  | 0:14  |
| Ethanol                                             | 25                                   | 0                                      | 0:59                                     | 0:31  | 0:26  |
|                                                     |                                      | 40                                     | 0:26                                     | 0:22  | 0:43  |
| Ethyl acetate                                       | 65                                   | 0                                      | 0:48                                     | 1:00  | 2:20  |
|                                                     |                                      | 40                                     | 0:20                                     | 0:20  | 0:31  |
| Ethyl acrylate                                      | 40                                   | 0                                      | 1:40                                     | 2:10  | 4:08  |
|                                                     |                                      | 40                                     | 0:30                                     | 0:30  | 0:50  |
| Ethyl benzene                                       | 100                                  | 0                                      | 6:10                                     | 9:31  | 7:44  |
|                                                     |                                      | 40                                     | 1:15                                     | 1:35  | 1:35  |
| Ethyl butyrate                                      | 70                                   | 0                                      | 4:34                                     | 6:22  | 8:00  |
|                                                     |                                      | 40                                     | 0:48                                     | 1:07  | 1:24  |
| Ethyl formate                                       | 40                                   | 0                                      | 0:25                                     | 0:29  | 1:05  |
|                                                     |                                      | 40                                     | 0:16                                     | 0:17  | 0:20  |
| Ethyl methacrylate                                  | 70                                   | 0                                      | 4:13                                     | 6:13  | 6:20  |
|                                                     |                                      | 40                                     | 0:47                                     | 1:01  | 1:01  |
| Ethyl propionate                                    | 65                                   | 0                                      | 1:40                                     | 2:48  | 4:10  |
|                                                     |                                      | 40                                     | 0:25                                     | 0:35  | 0:50  |
| Ethylene dibromide                                  | 50                                   | 0                                      | 5:20                                     | 4:51  | 15:00 |
|                                                     |                                      | 40                                     | 1:00                                     | 0:55  | 2:43  |

Table 10.16 Cont'd

| Compound                          | Relative response <sup>(1)</sup> (%) | Column temperature <sup>(2)</sup> (°C) | Column packing retention time (min:secs) |      |       |
|-----------------------------------|--------------------------------------|----------------------------------------|------------------------------------------|------|-------|
|                                   |                                      |                                        | B-8                                      | G-8  | T-8   |
| Ethylene dichloride               | 60                                   | 0                                      | 1:07                                     | 1:08 | 3:45  |
|                                   |                                      | 40                                     | 0:20                                     | 0:21 | 0:50  |
| Ethylene oxide                    | 70                                   | 0                                      | 0:10                                     | 0:13 | 0:20  |
|                                   |                                      | 40                                     | —                                        | —    | —     |
| Fluorotrichloromethane (Freon 11) | 10                                   | 0                                      | 0:15                                     | 0:18 | 0:17  |
|                                   |                                      | 40                                     | —                                        | —    | —     |
| Heptane                           | 75                                   | 0                                      | 0:50                                     | 2:20 | 0:27  |
|                                   |                                      | 40                                     | 0:20                                     | 0:30 | 0:16  |
| Hexane                            | 70                                   | 0                                      | 0:23                                     | 0:50 | 0:20  |
|                                   |                                      | 40                                     | 0:13                                     | 0:20 | 0:13  |
| Isoprene                          | 50                                   | 0                                      | 0:10                                     | 0:23 | 0:20  |
|                                   |                                      | 40                                     | 0:05                                     | 0:05 | 0:05  |
| Methane                           | 100                                  | 0                                      | 0:05                                     | 0:05 | 0:05  |
|                                   |                                      | 40                                     | —                                        | —    | —     |
| Methyl alcohol                    | 12                                   | 0                                      | 0:37                                     | 0:21 | 2:23  |
|                                   |                                      | 40                                     | 0:22                                     | 0:14 | 0:45  |
| Methyl acetate                    | 41                                   | 0                                      | 0:30                                     | 0:30 | 1:30  |
|                                   |                                      | 40                                     | 0:17                                     | 0:15 | 0:24  |
| Methyl acrylate                   | 40                                   | 0                                      | 0:50                                     | 0:58 | 2:30  |
|                                   |                                      | 40                                     | 0:20                                     | 0:21 | 0:37  |
| Methyl cyclohexane                | 100                                  | 0                                      | 0:54                                     | 2:37 | 0:25  |
|                                   |                                      | 40                                     | 0:18                                     | 0:33 | 0:17  |
| Methyl cyclopentane               | 80                                   | 0                                      | 0:22                                     | 1:02 | 0:17  |
|                                   |                                      | 40                                     | 0:05                                     | 0:19 | 0:05  |
| Methyl ethyl ketone               | 80                                   | 0                                      | 1:00                                     | 0:50 | 3:30  |
|                                   |                                      | 40                                     | 0:22                                     | 0:20 | 0:43  |
| Methyl isobutyl ketone            | 80                                   | 0                                      | 4:20                                     | 3:15 | 7:30  |
|                                   |                                      | 40                                     | 0:42                                     | 0:40 | 1:25  |
| Methyl methacrylate               | 50                                   | 0                                      | 1:41                                     | 2:22 | 4:08  |
|                                   |                                      | 40                                     | 0:27                                     | 0:31 | 0:55  |
| Methyl propyl ketone              | 70                                   | 0                                      | 2:20                                     | 2:05 | 6:14  |
|                                   |                                      | 40                                     | 0:33                                     | 0:32 | 0:52  |
| Nitromethane                      | 35                                   | 0                                      | 0:51                                     | 0:40 | 3:00  |
|                                   |                                      | 40                                     | 0:25                                     | 0:19 | 1:31  |
| 1-Nitropropane                    | 60                                   | 0                                      | 4:50                                     | 2:50 | 25:00 |
|                                   |                                      | 40                                     | 0:46                                     | 0:41 | 4:05  |
| 2-Nitropropane                    | 70                                   | 0                                      | 2:53                                     | 1:51 | 10:00 |
|                                   |                                      | 40                                     | 0:35                                     | 0:31 | 1:52  |
| Nonane                            | 90                                   | 0                                      | 7:26                                     | 8:00 | 2:32  |
|                                   |                                      | 40                                     | 1:08                                     | 2:40 | 0:42  |
| Octane                            | 80                                   | 0                                      | 2:47                                     | 7:39 | 1:07  |
|                                   |                                      | 40                                     | 0:39                                     | 1:09 | 0:27  |
| Pentane                           | 65                                   | 0                                      | 0:18                                     | 0:25 | 0:14  |
|                                   |                                      | 40                                     | 0:12                                     | 0:12 | 0:12  |
| Pentanol                          | 40                                   | 0                                      | 12:00                                    | 6:00 | 20:00 |
|                                   |                                      | 40                                     | 2:44                                     | 1:17 | 3:36  |
| Propane                           | 80                                   | 0                                      | 0:05                                     | 0:11 | 0:05  |
|                                   |                                      | 40                                     | —                                        | —    | —     |
| n-Propanol                        | 40                                   | 0                                      | 2:50                                     | 1:00 | 6:30  |
|                                   |                                      | 40                                     | 0:35                                     | 0:30 | 1:05  |
| 2-Propanol                        | 65                                   | 0                                      | 1:13                                     | 0:30 | 3:43  |
|                                   |                                      | 40                                     | 0:25                                     | 0:20 | 0:38  |
| n-Propyl acetate                  | 75                                   | 0                                      | 2:04                                     | 2:52 | 5:52  |
|                                   |                                      | 40                                     | 0:30                                     | 0:38 | 0:51  |

Table 10.16 Cont'd

| Compound                             | Relative response <sup>(1)</sup> (%) | Column temperature <sup>(2)</sup> (°C) | Column packing retention time (min:secs) |       |       |
|--------------------------------------|--------------------------------------|----------------------------------------|------------------------------------------|-------|-------|
|                                      |                                      |                                        | B-8                                      | G-8   | T-8   |
| <i>n</i> -Propyl ether               | 65                                   | 0                                      | 1:37                                     | 2:06  | 1:15  |
|                                      |                                      | 40                                     | 0:43                                     | 0:29  | 0:18  |
| <i>n</i> -Propyl formate             | 50                                   | 0                                      | 0:46                                     | 1:07  | 2:10  |
|                                      |                                      | 40                                     | 0:17                                     | 0:18  | 0:27  |
| Pyridine                             | 128                                  | 0                                      | 8:00                                     | 4:15  | –     |
|                                      |                                      | 40                                     | –                                        | 1:26  | –     |
| Styrene                              | 85                                   | 0                                      | 20:00                                    | 25:00 | 28:00 |
|                                      |                                      | 40                                     | 2:06                                     | 2:26  | 2:39  |
| 1,1,1,2-Tetrachloroethane            | 100                                  | 0                                      | 8:25                                     | 7:48  | 10:00 |
|                                      |                                      | 40                                     | 1:16                                     | 1:27  | 1:37  |
| 1,1,2,2-Tetrachloroethane            | 100                                  | 0                                      | 32:00                                    | 14:00 | 50:00 |
|                                      |                                      | 40                                     | 4:09                                     | 2:37  | 7:51  |
| Tetrachloroethylene                  | 70                                   | 0                                      | 3:00                                     | 5:45  | 2:10  |
|                                      |                                      | 40                                     | 0:41                                     | 1:06  | 0:33  |
| Tetrahydrofuran                      | 40                                   | 0                                      | 1:05                                     | 1:05  | 1:45  |
|                                      |                                      | 40                                     | 0:23                                     | 0:23  | 0:30  |
| Toluene                              | 110                                  | 0                                      | 2:30                                     | 4:05  | 4:30  |
|                                      |                                      | 40                                     | 0:38                                     | 0:47  | 0:53  |
| 1,1,1-Trichloroethane                | 105                                  | 0                                      | 0:31                                     | 1:10  | 0:47  |
|                                      |                                      | 40                                     | 0:15                                     | 0:23  | 0:20  |
| 1,1,2-Trichloroethane                | 85                                   | 0                                      | 5:13                                     | 3:43  | 15:00 |
|                                      |                                      | 40                                     | 0:40                                     | 0:45  | 2:30  |
| Trichloroethylene                    | 70                                   | 0                                      | 1:17                                     | 2:02  | 1:25  |
|                                      |                                      | 40                                     | 0:23                                     | 0:28  | 0:28  |
| Trichlorotrifluoroethane (Freon 113) | 80                                   | 0                                      | 0:15                                     | 0:30  | 0:16  |
|                                      |                                      | 40                                     | 0:13                                     | 0:14  | 0:13  |
| Triethylamine                        | 70                                   | 0                                      | –                                        | 2:49  | –     |
|                                      |                                      | 40                                     | –                                        | –     | –     |
| Vinyl acetate                        | 50                                   | 0                                      | 0:34                                     | 0:43  | 1:55  |
|                                      |                                      | 40                                     | 0:15                                     | 0:17  | 0:30  |
| Vinylidene chloride                  | 40                                   | 0                                      | 0:20                                     | 0:25  | 0:22  |
|                                      |                                      | 40                                     | 0:13                                     | 0:14  | 0:14  |
| <i>m</i> -Xylene                     | 111                                  | 0                                      | 2:39                                     | 12:03 | 8:31  |
|                                      |                                      | 40                                     | 0:39                                     | 1:43  | 1:17  |
| <i>o</i> -Xylene                     | 116                                  | 0                                      | 3:29                                     | 15:07 | 8:40  |
|                                      |                                      | 40                                     | 0:48                                     | 1:58  | 1:45  |
| <i>p</i> -Xylene                     | 116                                  | 0                                      | 2:46                                     | 12:25 | 8:23  |
|                                      |                                      | 40                                     | 0:39                                     | 1:42  | 1:19  |

B 3% Diisodecyl phthalate on Chromosorb W, AW, 60/80 mesh

G 10% SP – 2100 on Supelcoport, 60/80 mesh

T 10% 1,2,3-Tris(2-cyanoethoxy) propane on Chromosorb P, AW, 60/80 mesh

<sup>(1)</sup> Century organic vapour analysers are factory calibrated to measure 'total organic' vapours according to a standard (methane). Since different organic vapours interact with the flame ionization detector (FID) to varying extents, it is vital that the instrument user be aware of the magnitude of the variation in order to obtain the most accurate data. Each user must determine relative responses for the individual instrument.

<sup>(2)</sup> For chromatographic work, the OVA can be used with a variety of column lengths and packing materials. For highest accuracy, temperature control for the column is mandatory. This is accomplished using the portable isothermal pack (PIP) kit which is supplied with three 8 in (203 mm) columns packed with B, G and T materials respectively. Isothermal control is accomplished non-electrically using an ice-water mixture for 0 °C and a seeded eutectic mixture for 40 °C. The data listed are for comparison purposes only since retention time for a compound can vary according to the condition of the column packing material, packing procedure and chemical interaction among the components of a vapour mix.

A blank in the table indicates that no data are available for the analysis.

**Table 10.17 Compounds detectable by portable infrared analysis (MIRAN 1A)**

| <i>Compound</i>                                       | <i>Analytical Wavelength ( m)<sup>(1)</sup></i> | <i>Path length (m)<sup>(2)</sup></i> | <i>Absorbance<sup>(3)</sup></i> | <i>Minimum Detectable Concentration (ppm)<sup>(4)</sup></i><br>(20 metre cell) |
|-------------------------------------------------------|-------------------------------------------------|--------------------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Acetaldehyde                                          | 9.0                                             | 20.25                                | 0.23                            | 0.8                                                                            |
| Acetic acid                                           | 8.5                                             | 20.25                                | 0.044                           | 0.1                                                                            |
| Acetic anhydride                                      | 8.9                                             | 20.25                                | 0.18                            | 0.02                                                                           |
| Acetone                                               | 8.2                                             | 2.25                                 | 0.49                            | 0.09                                                                           |
| Acetonitrile                                          | 9.6                                             | 20.25                                | 0.005                           | 5.0                                                                            |
| Acetophenone                                          | 7.9                                             | 20.25                                | 0.5                             | 0.7                                                                            |
| Acetylene                                             | 3.03                                            | 6.75                                 | 0.19                            | 0.4                                                                            |
| Acetylene dichloride, <i>see</i> 1,2-Dichloroethylene |                                                 |                                      |                                 |                                                                                |
| Acetylene tetrabromide                                | 8.85                                            | 20.25                                | 0.0047                          | 0.1                                                                            |
| Acrolein                                              | 8.6                                             | 20.25                                | 0.0002                          | 0.3                                                                            |
| Acrylonitrile                                         | 10.5                                            | 20.25                                | 0.005                           | 0.2                                                                            |
| Allyl alcohol                                         | 9.8                                             | 20.25                                | 0.0055                          | 0.3                                                                            |
| Allyl chloride                                        | 10.8                                            | 20.25                                | 0.0032                          | 0.2                                                                            |
| Allylglycidylether                                    | 9.1                                             | 20.25                                | 0.08                            | 0.07                                                                           |
| 2-Aminoethanol, <i>see</i> Ethanolamine               |                                                 |                                      |                                 |                                                                                |
| Ammonia                                               | 10.4                                            | 20.25                                | 0.14                            | 0.2                                                                            |
| <i>n</i> -Amyl acetate                                | 8.0                                             | 0.75                                 | 0.12                            | 0.02                                                                           |
| Aniline                                               | 9.3                                             | 20.25                                | 0.011                           | 0.3                                                                            |
| Arsine                                                | 4.66                                            | 20.25                                | 0.0003                          | 0.1                                                                            |
| Arylam, <i>see</i> Carbaryl                           |                                                 |                                      |                                 |                                                                                |
| Benzene                                               | 14.87                                           | 20.25                                | 0.08                            | 0.3                                                                            |
| <i>p</i> -Benzoquinone, <i>see</i> Quinone            |                                                 |                                      |                                 |                                                                                |
| Benzyl chloride                                       | 7.9                                             | 20.25                                | 0.0012                          | 0.4                                                                            |
| Bisphenol A, <i>see</i> Diglycidyl ether              |                                                 |                                      |                                 |                                                                                |
| Bis(chloromethyl) ether                               | 8.99                                            | 20.25                                | 0.0016                          | 0.2                                                                            |
| Boron trifluoride                                     | 6.8                                             | 20.25                                | 0.006                           | 0.5                                                                            |
| Bromoform                                             | 8.7                                             | 20.25                                | 0.005                           | 0.05                                                                           |
| Butadiene, (1,3-butadiene)                            | 11.0                                            | 2.25                                 | 0.46                            | 0.2                                                                            |
| Butane                                                | 10.36                                           | 20.25                                | 0.03                            | 3.0                                                                            |
| Butanethiol, <i>see</i> Butyl mercaptan               |                                                 |                                      |                                 |                                                                                |
| 2-Butanone (MEK)                                      | 8.5                                             | 20.25                                | 0.55                            | 0.15                                                                           |
| 2-Butoxyethanol (butyl cellosolve)                    | 8.9                                             | 9.75                                 | 0.2                             | 0.08                                                                           |
| Butyl acetate ( <i>n</i> -butyl acetate)              | 8.1                                             | 3.75                                 | 0.53                            | 0.02                                                                           |
| sec-Butyl acetate                                     | 9.9                                             | 9.75                                 | 0.48                            | 0.15                                                                           |
| tert-Butyl acetate                                    | 9.9                                             | 9.75                                 | 0.36                            | 0.2                                                                            |
| <i>n</i> -Butyl alcohol                               | 9.6                                             | 8.25                                 | 0.15                            | 0.17                                                                           |
| sec-Butyl alcohol                                     | 10.1                                            | 9.75                                 | 0.15                            | 0.35                                                                           |
| tert-Butyl alcohol                                    | 8.2                                             | 20.75                                | 0.47                            | 0.05                                                                           |
| Butylamine                                            | 13.0                                            | 20.25                                | 0.025                           | 0.3                                                                            |

|                                                       |      |       |        |      |
|-------------------------------------------------------|------|-------|--------|------|
| Butyl ether                                           | 8.85 | 20.25 | 0.5    | 0.04 |
| Butyl carbitol                                        | 8.9  | 20.25 | 0.32   | 0.08 |
| <i>n</i> -Butyl glycidyl ether                        | 8.9  | 20.25 | 0.55   | 0.05 |
| Butyl mercaptan                                       | 3.37 | 20.25 | 0.04   | 0.08 |
| <i>p</i> -tert-Butyltoluene                           | 12.3 | 20.25 | 0.015  | 0.8  |
| Carbon disulphide                                     | 4.54 | 20.25 | 0.015  | 0.5  |
| Carbon dioxide                                        | 4.25 | 0.75  | 1.2    | 0.05 |
| Carbon monoxide                                       | 4.61 | 20.25 | 0.045  | 0.2  |
| Carbon tetrachloride                                  | 12.6 | 20.25 | 0.31   | 0.06 |
| Carbonyl sulphide                                     | 4.85 | 20.25 | 0.5    | 0.02 |
| Carbary <sup>(5)</sup>                                |      |       |        |      |
| Chlorinated camphene <sup>(5)</sup>                   |      |       |        |      |
| Chlorobenzene (monochlorobenzene)                     | 9.2  | 20.25 | 0.26   | 0.2  |
| Chlorobromomethane                                    | 8.1  | 9.75  | 0.29   | 0.2  |
| 2-Chloro-1,3-butadiene, <i>see</i> Chloroprene        |      |       |        |      |
| Chlorodifluoromethane (Freon 22)                      | 9.0  | 5.25  | 0.17   | 0.02 |
| 1-Chloro-2,3-Epoxypropane, <i>see</i> Epichlorohydrin |      |       |        |      |
| 2-Chloroethanol, <i>see</i> Ethylene chlorohydrin     |      |       |        |      |
| Chloroethylene, <i>see</i> Vinyl chloride             |      |       |        |      |
| Chloroform (trichloromethane)                         | 13.0 | 5.25  | 0.45   | 0.06 |
| 1-Chloro-1-nitropropane                               | 12.4 | 20.25 | 0.04   | 1.0  |
| Chloropentafluoroethane (Genetron 115)                | 8.1  | 5.25  | 0.7    | 0.02 |
| Chloropicrin (trichloronitromethane)                  | 11.5 | 20.25 | 0.002  | 0.05 |
| Chloroprene (2-chloro-1,3-butadiene)                  | 11.4 | 20.25 | 0.08   | 0.4  |
| Chlorotrifluoroethylene                               | 9.24 | 20.25 | 0.04   | 0.06 |
| Cresol (all isomers)                                  | 8.6  | 20.25 | 0.0066 | 0.3  |
| Crotonaldehyde (trans-2-butenal)                      | 8.7  | 20.25 | 0.01   | 0.1  |
| Cumene (isopropyl benzene)                            | 9.75 | 20.25 | 0.031  | 0.7  |
| Cyanogen                                              | 4.7  | 20.25 | 0.016  | 3.0  |
| Cyclohexane                                           | 3.4  | 2.25  | 0.56   | 0.03 |
| Cyclohexanol                                          | 9.3  | 20.25 | 0.28   | 0.10 |
| Cyclohexanone                                         | 8.3  | 20.25 | 0.054  | 0.5  |
| Cyclohexene                                           | 8.8  | 20.25 | 0.12   | 0.3  |
| Deuterium oxide                                       | 3.68 | 20.25 | 0.067  | 1.0  |
| DDVP, <i>see</i> Dichlorvos                           |      |       |        |      |
| Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)    | 8.5  | 20.25 | 0.335  | 0.08 |
| 1,2-Diaminoethane, <i>see</i> Ethylenediamine         |      |       |        |      |
| Diborane                                              | 3.9  | 20.25 | 0.0005 | 0.1  |
| Dibromochloropropane                                  | 8.27 | 20.25 | 0.19   | 0.2  |
| 1,2-Dibromotetrafluoroethane                          | 8.45 | 20.25 | 0.7    | 0.02 |
| <i>o</i> -Dichlorobenzene                             | 13.4 | 20.25 | 0.213  | 0.4  |
| <i>p</i> -Dichlorobenzene                             | 9.1  | 9.75  | 0.47   | 0.06 |
| Dichlorodifluoromethane (Freon 12)                    | 9.1  | 0.75  | 1.2    | 0.02 |
| 1,1-Dichloroethane                                    | 9.4  | 9.75  | 0.15   | 0.3  |
| 1,2-Dichloroethylene                                  | 12.1 | 0.75  | 0.1    | 0.07 |

**Table 10.17 Cont'd**

| <i>Compound</i>                                                              | <i>Analytical Wavelength ( m)<sup>(1)</sup></i> | <i>Path length (m)<sup>(2)</sup></i> | <i>Absorbance<sup>(3)</sup></i> | <i>Minimum Detectable Concentration (ppm)<sup>(4)</sup></i><br>(20 metre cell) |
|------------------------------------------------------------------------------|-------------------------------------------------|--------------------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Dichloroethyl ether                                                          | 8.85                                            | 20.25                                | 0.13                            | 0.06                                                                           |
| Dichloromethane, <i>see</i> Methylene chloride                               |                                                 |                                      |                                 |                                                                                |
| Dichloromonofluoromethane (Freon 21)                                         | 9.3                                             | 0.75                                 | 0.42                            | 0.08                                                                           |
| 1,1-Dichloro-1-nitroethane                                                   | 9.1                                             | 20.25                                | 0.1                             | 0.07                                                                           |
| 1,2-Dichloropropane, <i>see</i> Propylene dichloride                         |                                                 |                                      |                                 |                                                                                |
| Dichlorotetrafluoroethane (Freon 114)                                        | 8.4                                             | 0.75                                 | 1.43                            | 0.02                                                                           |
| Dichlorvos DDVP                                                              | 9.4                                             | 20.25                                | 0.0014                          | 0.02                                                                           |
| Diethylamine                                                                 | 8.8                                             | 20.25                                | 0.1                             | 0.2                                                                            |
| Diethylamino ethanol                                                         | 9.4                                             | 20.25                                | 0.08                            | 0.1                                                                            |
| Diethylether, <i>see</i> Ethyl ether                                         |                                                 |                                      |                                 |                                                                                |
| Diethyl ketone                                                               | 9.0                                             | 20.25                                | 0.2                             | 0.1                                                                            |
| Diethyl malonate                                                             | 9.5                                             | 20.25                                | 0.11                            | 0.05                                                                           |
| Difluorodibromomethane                                                       | 9.2                                             | 2.25                                 | 0.36                            | 0.02                                                                           |
| Diglycidyl ether <sup>(6)</sup>                                              |                                                 |                                      |                                 |                                                                                |
| Dihydroxybenzene, <i>see</i> Hydroquinone                                    |                                                 |                                      |                                 |                                                                                |
| Diisobutyl ketone                                                            | 8.6                                             | 20.25                                | 0.12                            | 0.2                                                                            |
| Diisopropylamine                                                             | 8.5                                             | 20.25                                | 0.026                           | 0.1                                                                            |
| 1,2-Dimethoxyethane                                                          | 8.8                                             | 5.25                                 | 0.3                             | 0.1                                                                            |
| Dimethoxymethane, <i>see</i> Methylal                                        |                                                 |                                      |                                 |                                                                                |
| N,N-Dimethylacetamide                                                        | 9.9                                             | 20.25                                | 0.02                            | 0.3                                                                            |
| Dimethylamine                                                                | 8.7                                             | 20.25                                | 0.02                            | 0.5                                                                            |
| Dimethylaminobenzene, <i>see</i> Xylidene                                    |                                                 |                                      |                                 |                                                                                |
| Dimethylaniline (N, N dimethyl aniline)                                      | 8.6                                             | 20.25                                | 0.015                           | 0.2                                                                            |
| Dimethylbenzene, <i>see</i> Xylene                                           |                                                 |                                      |                                 |                                                                                |
| Dimethylformamide                                                            | 9.2                                             | 20.25                                | 0.063                           | 0.1                                                                            |
| 2,6-Dimethylheptanone, <i>see</i> Diisobutyl ketone                          |                                                 |                                      |                                 |                                                                                |
| Dimethylsulphate                                                             | 9.9                                             | 20.25                                | 0.04                            | 0.02                                                                           |
| Dimethyl sulphoxide                                                          | 9.0                                             | 20.25                                | 0.5                             | 0.2                                                                            |
| Dioxane (diethylene dioxide)                                                 | 8.9                                             | 5.25                                 | 0.38                            | 0.05                                                                           |
| Diphenylmethane diisocyanate, <i>see</i> Methylene bisphenyl isocyanate, MDI |                                                 |                                      |                                 |                                                                                |
| Enflurane                                                                    | 8.7                                             | 20.25                                | 0.10                            | 0.01                                                                           |
| Epichlorohydrin                                                              | 11.8                                            | 20.25                                | 0.013                           | 0.3                                                                            |
| 1,2-Epoxypropane, <i>see</i> Propylene oxide                                 |                                                 |                                      |                                 |                                                                                |
| 2,3-Epoxy-1-propanol, <i>see</i> Glycidol                                    |                                                 |                                      |                                 |                                                                                |
| Ethanethiol, <i>see</i> Ethyl mercaptan                                      |                                                 |                                      |                                 |                                                                                |
| Ethane                                                                       | 12.1                                            | 20.25                                | 0.15                            | 3.0                                                                            |
| Ethanolamine                                                                 | 13.0                                            | 20.25                                | 0.0017                          | 1.2                                                                            |
| 2-Ethoxyethanol (cellosolve)                                                 | 8.9                                             | 2.25                                 | 0.24                            | 0.06                                                                           |

|                                                                            |       |       |       |      |
|----------------------------------------------------------------------------|-------|-------|-------|------|
| 2-Ethoxyethyl acetate (cellosolve acetate)                                 | 8.8   | 8.25  | 0.58  | 0.03 |
| Ethyl acetate                                                              | 8.0   | 0.75  | 0.39  | 0.02 |
| Ethyl acrylate                                                             | 8.4   | 20.25 | 0.33  | 0.04 |
| Ethyl alcohol (ethanol)                                                    | 9.5   | 2.25  | 0.5   | 0.2  |
| Ethylamine                                                                 | 3.4   | 20.25 | 0.015 | 0.2  |
| Ethyl sec-amyl ketone (5-methyl-3-heptanone)                               | 9.0   | 20.25 | 0.04  | 0.3  |
| Ethylbenzene                                                               | 9.7   | 20.25 | 0.06  | 1.0  |
| Ethyl bromide                                                              | 8.0   | 5.25  | 0.17  | 0.2  |
| Ethyl butyl ketone (3-heptanone)                                           | 9.0   | 20.25 | 0.12  | 0.2  |
| Ethyl chloride                                                             | 10.4  | 20.25 | 0.62  | 0.8  |
| Ethyl ether                                                                | 8.8   | 2.25  | 0.58  | 0.03 |
| Ethyl formate                                                              | 8.5   | 2.25  | 0.1   | 0.06 |
| 2-Ethyl hexanol                                                            | 9.7   | 20.25 | 0.02  | 0.2  |
| Ethyl mercaptan                                                            | 3.3   | 20.25 | 0.029 | 0.8  |
| Ethyl silicate                                                             | 9.1   | 5.25  | 0.93  | 0.02 |
| Ethylene                                                                   | 10.6  | 20.25 | 0.12  | 0.5  |
| Ethylene chlorohydrin                                                      | 9.3   | 20.25 | 0.026 | 0.08 |
| Ethylenediamine                                                            | 13.0  | 20.25 | 0.035 | 0.4  |
| Ethylene dibromide (1,2-dibromoethane)                                     | 8.45  | 20.25 | 0.07  | 0.1  |
| Ethylene dichloride (1,2-dichloroethane)                                   | 8.1   | 20.25 | 0.09  | 0.3  |
| Ethylene glycol monomethyl ether acetate,<br>see Methyl cellosolve acetate |       |       |       |      |
| Ethylene oxide                                                             | 11.8  | 20.25 | 0.12  | 0.4  |
| Ethylidene chloride, see 1,1-Dichloroethane                                |       |       |       |      |
| Fluorobenzene                                                              | 8.1   | 20.25 | 0.4   | 0.06 |
| Fluorotrichloromethane (Freon 11)                                          | 11.9  | 0.75  | 1.7   | 0.01 |
| Fluorene                                                                   | 8.5   | 20.25 | 0.086 | 0.01 |
| Formaldehyde                                                               | 3.58  | 20.25 | 0.015 | 0.2  |
| Formic acid                                                                | 8.9   | 20.25 | 0.055 | 0.05 |
| Furfural                                                                   | 13.3  | 20.25 | 0.05  | 0.1  |
| Furfuryl alcohol                                                           | 9.8   | 20.25 | 0.09  | 0.3  |
| Glycidol (2,3-epoxy-1-propanol)                                            | 9.9   | 20.25 | 0.020 | 1.3  |
| Glycol monoethyl ether, see 2-Ethoxyethanol                                |       |       |       |      |
| Guthion <sup>(R)</sup> , see Azinphosmethyl                                |       |       |       |      |
| Halothane                                                                  | 12.3  | 20.25 | 0.027 | 0.08 |
| Heptane ( <i>n</i> -heptane)                                               | 3.4   | 0.75  | 0.29  | 0.01 |
| 1-Heptanol                                                                 | 9.5   | 20.25 | 0.2   | 0.1  |
| Hexachloroethane                                                           | 12.8  | 20.25 | 0.04  | 0.03 |
| Hexafluoropropene                                                          | 8.3   | 20.25 | 0.16  | 0.06 |
| Hexane ( <i>n</i> -hexane)                                                 | 3.4   | 0.75  | 0.26  | 0.02 |
| 2-Hexanone                                                                 | 8.6   | 20.25 | 0.42  | 0.1  |
| Hexone (methyl isobutyl ketone)                                            | 8.5   | 20.25 | 0.31  | 0.2  |
| sec-Hexyl acetate                                                          | 9.8   | 9.75  | 0.1   | 0.2  |
| Hydrazine                                                                  | 10.55 | 20.25 | 0.001 | 0.25 |
| Hydrogen chloride                                                          | 3.4   | 20.25 | 0.002 | 1.0  |



**Table 10.17 Cont'd**

| <i>Compound</i>                                    | <i>Analytical Wavelength ( m)<sup>(1)</sup></i> | <i>Path length (m)<sup>(2)</sup></i> | <i>Absorbance<sup>(3)</sup></i> | <i>Minimum Detectable Concentration (ppm)<sup>(4)</sup></i><br>(20 metre cell) |
|----------------------------------------------------|-------------------------------------------------|--------------------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Hydrogen cyanide                                   | 3.04                                            | 20.25                                | 0.0083                          | 0.4                                                                            |
| Hydroquinone <sup>(5)</sup>                        |                                                 |                                      |                                 |                                                                                |
| Isoamyl acetate                                    | 9.4                                             | 9.75                                 | 0.27                            | 0.14                                                                           |
| Isoamyl alcohol                                    | 9.4                                             | 9.75                                 | 0.22                            | 0.13                                                                           |
| Isobutyl acetate                                   | 8.2                                             | 2.25                                 | 0.4                             | 0.02                                                                           |
| Isobutyl alcohol                                   | 9.6                                             | 8.25                                 | 0.30                            | 0.08                                                                           |
| Isodecanol                                         | 9.6                                             | 20.25                                | 0.25                            | 0.3                                                                            |
| Isoflurane                                         | 8.25                                            | 20.25                                | 0.07                            | 0.02                                                                           |
| Isophorone                                         | 3.4                                             | 20.25                                | 0.12                            | 0.4                                                                            |
| Isoprene                                           | 11.2                                            | 5.25                                 | 0.078                           | 0.2                                                                            |
| Isopropyl acetate                                  | 8.0                                             | 2.25                                 | 0.63                            | 0.02                                                                           |
| Isopropyl alcohol                                  | 8.7                                             | 6.75                                 | 0.45                            | 0.12                                                                           |
| Isopropylamine                                     | 8.5                                             | 20.25                                | 0.025                           | 0.1                                                                            |
| Isopropyl ether                                    | 8.9                                             | 0.75                                 | 0.17                            | 0.07                                                                           |
| LPG (liquefied petroleum gas)                      | 3.4                                             | 0.75                                 | 0.24                            | 0.4                                                                            |
| Mesityl oxide                                      | 8.2                                             | 20.25                                | 0.06                            | 0.2                                                                            |
| Methane                                            | 7.65                                            | 20.25                                | 0.072                           | 0.2                                                                            |
| Methanethiol, see Methyl mercaptan                 |                                                 |                                      |                                 |                                                                                |
| Methoxyflurane                                     | 12.0                                            | 20.25                                | 0.03                            | 0.07                                                                           |
| 2-Methoxyethanol, see Methyl cellosolve            |                                                 |                                      |                                 |                                                                                |
| Methyl acetate                                     | 9.5                                             | 5.25                                 | 0.31                            | 0.2                                                                            |
| Methyl acetylene (propyne)                         | 7.9                                             | 20.25                                | 0.77                            | 1.0                                                                            |
| Methyl acrylate                                    | 8.4                                             | 20.25                                | 0.15                            | 0.03                                                                           |
| Methylal (dimethoxymethane)                        | 9.5                                             | 0.75                                 | 0.43                            | 0.05                                                                           |
| Methyl alcohol (methanol)                          | 9.5                                             | 5.25                                 | 0.3                             | 0.1                                                                            |
| Methylamine                                        | 3.4                                             | 20.25                                | 0.02                            | 0.1                                                                            |
| Methyl amyl alcohol, see Methyl isobutyl carbinol  |                                                 |                                      |                                 |                                                                                |
| Methyl <i>n</i> -amyl ketone (2-heptanone)         | 8.6                                             | 9.75                                 | 0.14                            | 0.2                                                                            |
| Methyl bromide                                     | 7.6                                             | 20.25                                | 0.021                           | 0.4                                                                            |
| Methyl butyl ketone, see 2-Hexanone                |                                                 |                                      |                                 |                                                                                |
| Methyl cellosolve                                  | 8.8                                             | 20.25                                | 0.19                            | 0.05                                                                           |
| Methyl cellosolve acetate                          | 8.0                                             | 20.25                                | 0.39                            | 0.02                                                                           |
| Methyl chloride                                    | 13.4                                            | 20.25                                | 0.14                            | 1.5                                                                            |
| Methyl chloroform                                  | 9.2                                             | 2.25                                 | 0.4                             | 0.06                                                                           |
| Methylcyclohexane                                  | 3.4                                             | 2.25                                 | 0.84                            | 0.04                                                                           |
| Methylcyclohexanol                                 | 9.5                                             | 20.25                                | 0.24                            | 0.2                                                                            |
| <i>o</i> -Methylcyclohexanone                      | 8.9                                             | 20.25                                | 0.18                            | 0.3                                                                            |
| Methylene bisphenyl isocyanate, MDI <sup>(5)</sup> |                                                 |                                      |                                 |                                                                                |
| Methylene chloride                                 | 13.4                                            | 0.75                                 | 0.25                            | 0.2                                                                            |

|                                                  |      |       |         |       |
|--------------------------------------------------|------|-------|---------|-------|
| Methyl ethyl ketone (MEK), <i>see</i> 2-Butanone |      |       |         |       |
| N-methyl formamide                               | 8.4  | 5.25  | 0.065   | 0.2   |
| Methyl formate                                   | 8.5  | 0.75  | 0.13    | 0.02  |
| Methyl iodide                                    | 7.9  | 20.25 | 0.009   | 0.4   |
| Methyl isoamyl ketone                            | 8.6  | 20.25 | 0.6     | 0.04  |
| Methyl isobutyl carbinol                         | 8.7  | 20.25 | 0.053   | 0.25  |
| Methyl isobutyl ketone, <i>see</i> Hexone        |      |       |         |       |
| Methyl isocyanate                                | 11.6 | 20.25 | 0.00003 | 0.6   |
| Methyl isopropyl ketone                          | 8.8  | 20.25 | 0.1     | 0.3   |
| Methyl mercaptan                                 | 3.38 | 20.25 | 0.008   | 0.4   |
| Methyl methacrylate                              | 8.5  | 2.25  | 0.21    | 0.03  |
| Methyl propyl ketone, <i>see</i> 2-Pentanone     |      |       |         |       |
| $\alpha$ -Methyl styrene                         | 11.1 | 20.25 | 0.3     | 0.3   |
| Monomethylaniline                                | 7.9  | 20.25 | 0.007   | 0.2   |
| Morpholine                                       | 9.0  | 20.25 | 0.05    | 0.2   |
| Nickel carbonyl                                  | 4.86 | 20.25 | 0.0003  | 0.005 |
| Nitric oxide (NO)                                | 5.3  | 20.25 | 0.015   | 2.0   |
| Nitrobenzene                                     | 11.8 | 20.25 | 0.005   | 0.2   |
| Nitroethane                                      | 9.0  | 20.25 | 0.08    | 0.6   |
| Nitrogen dioxide (NO <sub>2</sub> )              | 6.17 | 20.25 | 0.048   | 0.1   |
| Nitrogen trifluoride                             | 11.0 | 20.25 | 0.35    | 0.03  |
| Nitromethane                                     | 9.3  | 20.25 | 0.056   | 0.9   |
| Nitrotoluene                                     | 11.8 | 20.25 | 0.0076  | 0.7   |
| Nitrotrichloromethane, <i>see</i> Chloropicrin   |      |       |         |       |
| Nitrous oxide                                    | 4.50 | 20.25 | 0.3     | 0.07  |
| Octane                                           | 3.4  | 0.75  | 0.40    | 0.02  |
| Pentane                                          | 3.4  | 0.75  | 0.42    | 0.02  |
| 2-Pentanone                                      | 8.5  | 5.25  | 0.23    | 0.1   |
| Perchloroethylene                                | 10.9 | 5.25  | 0.63    | 0.05  |
| Petroleum distillates                            | 3.4  | 2.25  | 0.65    | 0.02  |
| Phenyl ether-biphenyl mixture (vapour)           | 8.1  | 20.25 | 0.011   | 0.04  |
| Phenylethylene, <i>see</i> Styrene               |      |       |         |       |
| Phenylhydrazine                                  | 8.5  | 20.25 | 0.0029  | 0.9   |
| Phosgene (carbonyl chloride)                     | 11.8 | 20.25 | 0.0027  | 0.03  |
| Phosphine                                        | 10.1 | 20.25 | 0.0003  | 1.0   |
| Picric acid <sup>(5)</sup>                       |      |       |         |       |
| Propane                                          | 3.35 | 2.25  | 0.79    | 0.03  |
| <i>n</i> -Propyl acetate                         | 8.1  | 0.75  | 0.18    | 0.02  |
| Propyl alcohol                                   | 9.4  | 9.75  | 0.39    | 0.2   |
| <i>n</i> -Propyl chloride                        | 7.9  | 20.25 | 0.2     | 0.7   |
| <i>n</i> -Propyl nitrate                         | 10.4 | 20.25 | 0.11    | 0.1   |
| Propylene dichloride                             | 9.8  | 20.25 | 0.12    | 0.3   |
| Propylene oxide                                  | 12.0 | 20.25 | 0.32    | 0.3   |
| Propyne, <i>see</i> Methyl acetylene             |      |       |         |       |
| Pyridine                                         | 14.2 | 20.25 | 0.05    | 0.2   |

**Table 10.17 Cont'd**

| <i>Compound</i>                                    | <i>Analytical Wavelength ( m)<sup>(1)</sup></i> | <i>Path length (m)<sup>(2)</sup></i> | <i>Absorbance<sup>(3)</sup></i> | <i>Minimum Detectable Concentration (ppm)<sup>(4)</sup></i><br>(20 metre cell) |
|----------------------------------------------------|-------------------------------------------------|--------------------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Quinone <sup>(5)</sup>                             |                                                 |                                      |                                 |                                                                                |
| Stoddard solvent                                   | 3.4                                             | 0.75                                 | 0.39                            | 0.01                                                                           |
| Styrene                                            | 11.0                                            | 12.75                                | 0.16                            | 0.2                                                                            |
| Sulphur dioxide                                    | 8.6                                             | 20.25                                | 0.003                           | 0.5                                                                            |
| Sulphur hexafluoride                               | 10.7                                            | 0.75                                 | 0.7                             | 0.02                                                                           |
| Sulphuryl fluoride                                 | 11.5                                            | 20.25                                | 0.10                            | 0.04                                                                           |
| Systox, see Demeton <sup>(R)</sup>                 |                                                 |                                      |                                 |                                                                                |
| 1,1,2,2-Tetrachloro-1,2-difluoroethane (Freon 112) | 9.7                                             | 0.75                                 | 0.19                            | 0.06                                                                           |
| 1,1,2,2-Tetrachloroethane                          | 8.3                                             | 20.25                                | 0.014                           | 0.2                                                                            |
| 1,1,1,2-Tetrachloroethane                          | 10.4                                            | 20.25                                | 0.4                             | 0.2                                                                            |
| Tetrachloroethylene, see Perchloroethylene         |                                                 |                                      |                                 |                                                                                |
| Tetrachloromethane, see Carbon tetrachloride       |                                                 |                                      |                                 |                                                                                |
| Tetrahydrofuran                                    | 9.2                                             | 9.75                                 | 0.47                            | 0.2                                                                            |
| Tetryl <sup>(5)</sup>                              |                                                 |                                      |                                 |                                                                                |
| Toluene                                            | 13.7                                            | 6.75                                 | 0.38                            | 0.5                                                                            |
| o-Toluidine                                        | 13.5                                            | 20.25                                | 0.029                           | 0.5                                                                            |
| Toxaphene, see Chlorinated camphene                |                                                 |                                      |                                 |                                                                                |
| Tributyl phosphate                                 | 10.7                                            | 20.25                                | 0.020                           | 0.3                                                                            |
| 1,1,1-Trichloroethane, see Methyl chloroform       |                                                 |                                      |                                 |                                                                                |
| 1,1,2-Trichloroethane                              | 11.8                                            | 5.25                                 | 0.27                            | 0.1                                                                            |
| Trichloroethylene                                  | 12.4                                            | 20.25                                | 0.16                            | 0.4                                                                            |
| Trichloromethane, see Chloroform                   |                                                 |                                      |                                 |                                                                                |
| 1,2,3-Trichloropropane                             | 8.4                                             | 0.75                                 | 0.46                            | 0.02                                                                           |
| 1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)  | 9.3                                             | 20.25                                | 0.077                           | 0.3                                                                            |
| Trifluoromonobromoethane (Freon 13B1)              | 8.3                                             | 0.75                                 | 1.5                             | 0.03                                                                           |
| 2,4,6-Trinitrophenol, see Picric acid              |                                                 |                                      |                                 |                                                                                |
| 2,4,6-Trinitrophenylmethyl-nitramenine, see Tetryl |                                                 |                                      |                                 |                                                                                |
| Turpentine                                         | 3.4                                             | 2.25                                 | 0.13                            | 0.02                                                                           |
| Vinyl benzene, see Styrene                         |                                                 |                                      |                                 |                                                                                |
| Vinyl acetate                                      | 8.1                                             | 20.25                                | 0.37                            | 0.02                                                                           |
| Vinyl bromide                                      | 10.85                                           | 20.25                                | 0.096                           | 0.4                                                                            |
| Vinyl chloride                                     | 10.9                                            | 20.25                                | 0.0017                          | 0.3                                                                            |
| Vinyl cyanide, see Acrylonitrile                   |                                                 |                                      |                                 |                                                                                |
| Vinylidene chloride                                | 9.18                                            | 20.25                                | 0.24                            | 0.1                                                                            |
| Vinyl toluene                                      | 11.1                                            | 20.25                                | 0.2                             | 0.4                                                                            |
| Xylene (xylol)                                     | 12.6                                            | 20.25                                | 0.33                            | 0.6                                                                            |
| Xylidene                                           | 7.2                                             | 20.25                                | 0.056                           | 0.2                                                                            |

- (1) The analytical wavelength has usually been chosen as that of the strongest band in the spectrum which is free from interference due to atmospheric water and CO<sub>2</sub>. If more than one infra-red absorbing material is present in the air in significant concentration, the use of another analytical wavelength may be necessary.
- (2) Path lengths are chosen to optimize readings at the exposure limits. All measurements were made using a 1 mm slit.
- (3) Equivalent to the OSHA limit. Absorbance less than the tabulated value indicates concentrations below the exposure limits regardless of the presence of interfering compounds.
- (4) The concentration that would produce an absorbance equal to the peak-to-peak noise of the instrument.
- (5) Solid or vapour pressure too low for analysis.
- (6) Difficult to obtain commercially.

**Table 10.18(a) Substances for which colour detector tubes are available from one supplier (Drager) – short-term tubes**

| <i>Substance</i>                      | <i>Measuring range</i>                                                |
|---------------------------------------|-----------------------------------------------------------------------|
| Acetaldehyde                          | 0.2–5 ppm<br>10–150 ppm<br>100–1000 ppm                               |
| Acetic acid                           | 1–15 ppm<br>20–320 ppm                                                |
| Acetic anhydride                      | 20–320 ppm                                                            |
| Acetone                               | 100–12 000 ppm                                                        |
| Acetonitrile                          | 40–1000 ppm                                                           |
| Acetylene                             | 25–300 ppm<br>100–2500 ppm<br>500–3000 ppm                            |
| Acrolein                              | 0.1–10 ppm                                                            |
| Acrylonitrile                         | 0.5–20 ppm<br>5–30 ppm<br>25–250 ppm                                  |
| Alcohols (general)                    | 25–5000 ppm<br>100–3000 ppm                                           |
| Aliphatic hydrocarbons (bp 50–200 °C) | 2–23 mg/l                                                             |
| Allyl propyl disulphide               | *                                                                     |
| Amines (general)                      | *                                                                     |
| Aminobutane                           | *                                                                     |
| Aminoethanol                          | 0.5–6 ppm                                                             |
| 1-Aminopropane                        | 2–30 ppm<br>5–60 ppm                                                  |
| 2-Aminopropane                        | 2–30 ppm<br>5–60 ppm                                                  |
| Ammonia                               | 0.25–3 ppm<br>2–30 ppm<br>2.5–100 ppm<br>5–700 ppm<br>500–100 000 ppm |
| iso-Amyl acetate                      | 200–1000 ppm                                                          |
| n-Amyl acetate                        | 200–1000 ppm                                                          |
| Aniline                               | 0.5–10 ppm<br>1–20 ppm                                                |
| o-Anisidine                           | 1–20 ppm                                                              |
| Antimony hydride                      | 0.05–3 ppm                                                            |
| Arsenic trioxide/pentoxide            | 0.2 mg/m <sup>3</sup>                                                 |
| Arsine                                | 0.05–60 ppm                                                           |
| Aziridine                             | 0.25–3 ppm                                                            |
| Benzene                               | 0.5–10 ppm<br>2–60 ppm<br>5–50 ppm<br>15–420 ppm                      |
| Benzyl chloride                       | 0.2–8 ppm<br>1–15 ppm                                                 |
| Biphenyl ether                        | *                                                                     |
| bis (2-Chloromethyl) ether            | *                                                                     |
| bis (Dimethylaminoethyl) ether        | *                                                                     |
| Bromine                               | 0.2–30 ppm<br>50–500 ppm                                              |
| Bromobenzene                          | 10–500 ppm                                                            |
| Bromochlorodifluoromethane            | *                                                                     |
| Bromochloromethane                    | 30–350 ppm                                                            |
| 1-Bromo-2-chloropropane               | *                                                                     |
| Bromoethane                           | 20–200 ppm<br>40–400 ppm                                              |

Table 10.18(a) Cont'd

| <i>Substance</i>              | <i>Measuring range</i>                                                                            |
|-------------------------------|---------------------------------------------------------------------------------------------------|
| Bromomethane                  | 20–200 ppm<br>40–400 ppm<br>500–25 000 ppm                                                        |
| Butadiene                     | 1–60 ppm<br>50–1000 ppm<br>100–1200 ppm                                                           |
| iso-Butane                    | 100–1000 ppm                                                                                      |
| <i>n</i> -Butane              | 100–8000 ppm                                                                                      |
| Butane thiol                  | *                                                                                                 |
| iso-Butanol                   | 40–1000 ppm                                                                                       |
| <i>n</i> -Butanol             | 30–50 ppm<br>100–5000 ppm                                                                         |
| Butan-2-one                   | 100–12 000 ppm                                                                                    |
| Buten-2-al                    | *                                                                                                 |
| 2-Butoxyethanol               | *                                                                                                 |
| 2-Butoxyethyl acetate         | *                                                                                                 |
| <i>n</i> -Butyl acetate       | 200–3000 ppm                                                                                      |
| Butyl acrylate                | *                                                                                                 |
| <i>n</i> -Butylamine          | 5–60 ppm<br>0.075–15 vol %                                                                        |
| Butyl chloroformate           | *                                                                                                 |
| <i>n</i> -Butylethylamine     | *                                                                                                 |
| Butyl glycol                  | *                                                                                                 |
| Butyl mercaptan               | *                                                                                                 |
| Butyl methacrylate            | *                                                                                                 |
| <i>p</i> -tert-Butyl toluene  | *                                                                                                 |
| iso-Butyraldehyde             | *                                                                                                 |
| <i>n</i> -Butyraldehyde       | *                                                                                                 |
| Calcium chromate              | *                                                                                                 |
| Carbonization untreated gases | *                                                                                                 |
| Carbon dioxide                | 100–3000 ppm<br>0.01–0.3 vol %<br>0.1–6 vol %<br>0.5–10 vol %<br>1–20%<br>5–60%                   |
| Carbon disulphide             | 3–95 ppm<br>2.5–120 ppm<br>0.1–60 mg/l                                                            |
| Carbon monoxide               | 2–300 ppm<br>5–250 ppm<br>5–700 ppm<br>8–150 ppm<br>10–3000 ppm<br>0.001–0.3 vol %<br>0.3–7 vol % |
| Carbonyl sulphide             | *                                                                                                 |
| Carbon tetrachloride          | 1–15 ppm<br>5–50 ppm                                                                              |
| Chlorine                      | 0.2–30 ppm<br>50–500 ppm                                                                          |
| Chlorine anhydrate            | *                                                                                                 |
| Chlorine dioxide              | 0.1–1.5 ppm                                                                                       |
| Chloroacetic acid             | 2–30 ppm                                                                                          |
| Chloroacetyl chloride         | *                                                                                                 |
| Chlorobenzene                 | 5–200 ppm                                                                                         |
| 2-Chloro-1,3-butadiene        | 5–90 ppm                                                                                          |

Table 10.18(a) Cont'd

| <i>Substance</i>              | <i>Measuring range</i> |
|-------------------------------|------------------------|
| 1-Chlorobutane                | 10–60 ppm              |
| 2-Chlorobutane                | 10–60 ppm              |
| Chlorobromomethane            | *                      |
| 4-Chlorobutyl chloride        | 0.5–4.5 ppm            |
| Chlorodifluoromethane         | *                      |
| 1-Chloro-2,3-epoxypropane     | *                      |
| Chloroethane                  | 5–50 ppm               |
| 2-Chloroethanol               | *                      |
| Chloroform                    | 2–10 ppm               |
| Chloroformates                | 0.2–10 ppm             |
| <i>o,m,p</i> -Chlorophenol    | *                      |
| Chloropicrin                  | 1–15 ppm               |
| Chloroprene                   | 5–90 ppm               |
| <i>o,m,p</i> -Chlorotoluene   | 5–50 ppm               |
|                               | 50–400 ppm             |
| Chromates (alkali)            | *                      |
| Coke oven gas                 | *                      |
| Cresol                        | 0.8–16 ppm             |
| Crotonaldehyde                | *                      |
| Crude petroleum               | *                      |
| Cumene                        | 30–400 ppm             |
|                               | 50–400 ppm             |
|                               | 100–1800 ppm           |
| Cyanides (Na, K, Ca)          | 2–15 mg/m <sup>3</sup> |
| Cyanogen chloride             | 0.25–5 ppm             |
| Cyclohexane                   | 100–1500 ppm           |
| Cyclohexanol                  | *                      |
| Cyclohexanone                 | 25–100 ppm             |
| Cyclohexene                   | *                      |
| Cyclohexylamine               | 2–30 ppm               |
| Cyclopentadiene               | *                      |
| Cyclopentane                  | 100–1500 ppm           |
| Cyclopropane                  | 100–1500 ppm           |
| Decane                        | 10–200 ppm             |
| Decene                        | 10–200 ppm             |
| Dementon                      | *                      |
| Denmenton methyl              | *                      |
| 1,2-Diaminoethane             | 0.5–12 ppm             |
| Diaminotoluene                | *                      |
| Dibenzylamine                 | 0.25–3 ppm             |
|                               | 5–60 ppm               |
| 1,2-Dibromo-3-chloropropane   | 5–50 ppm               |
| Dibromofluoromethane          | *                      |
| 1,2-Dibromoethane             | 5–50 ppm               |
| Dibutylamine                  | 2.5–30 ppm             |
| Dibutylether                  | 100–4000 ppm           |
| <i>o,m,p</i> -Dichlorobenzene | *                      |
| 1,4-Dichlorobut-2-ene         | *                      |
| Dichlorodiisopropyl ether     | *                      |
| Dichlorodimethyl ether        | *                      |
| 1,2-Dichloroethane            | 10–100 ppm             |
| 1,1-Dichloroethylene          | 0.38–3 ppm             |
| 1,2-Dichloroethylene          | 7.5–75 ppm             |
| Dichlorodifluoromethane       | *                      |
| 1,1-Dichloro-1-fluoroethane   | *                      |
| Dichlorofluoromethane         | *                      |
| Dichloromethane               | 10–2000                |

Table 10.18(a) Cont'd

| <i>Substance</i>                        | <i>Measuring range</i>   |
|-----------------------------------------|--------------------------|
| 3,3-Dichloro-1,1,2,2-pentachloropropane | *                        |
| 1,3-Dichloro-1,1,2,2-pentachloropropane | *                        |
| Dichloroprene                           | *                        |
| 1,2-Dichloropropane                     | 50–100 ppm               |
| 1,3-Dichloropropene                     | 5–50 ppm                 |
| 1,2-Dichloro-1,1,2,2-tetrafluoroethane  | *                        |
| 2,2-Dichloro-1,1,1-trifluoroethane      | *                        |
| 1,1-Dichloro-2,2,2-trifluoroethane      | *                        |
| Dichlorotoluene                         | *                        |
| Dicyclopentadiene                       | 1.5–15 mg/m <sup>3</sup> |
| Diesel                                  | *                        |
| Diethanolamine                          | *                        |
| Diethylamine                            | 5–60 ppm                 |
|                                         | 0.05–10 vol %            |
| 2-Diethylaminoethanol                   | 0.5–10 ppm               |
| Diethylbenzene                          | *                        |
| Diethylcarbonate                        | *                        |
| Diethylene dioxide                      | 12.5–175 ppm             |
| Diethylene glycol                       | *                        |
| Diethylenediamine                       | 5–60 ppm                 |
| Diethylenetriamine                      | *                        |
| Diethyl ether                           | 10–4000 ppm              |
| Diethyl sulphate                        | *                        |
| Diethyl sulphide                        | 0.1–1.5 ppm              |
| Difluorobromomethane                    | *                        |
| Diisobutylene                           | 2.5–30 ppm               |
| Diisobutyl ketone                       | *                        |
| Diisopropanolamine                      | *                        |
| Diisopropylamine                        | *                        |
| Dimethoxyethane                         | *                        |
| Dimethoxymethane                        | *                        |
| Dimethyl acetamide                      | 100–400 ppm              |
| Dimethylamine                           | 0.25–6 ppm               |
|                                         | 5–60 ppm                 |
| Dimethylaminoacetonitrile               | *                        |
| Dimethylaminopropylamine                | 5–60 ppm                 |
| <i>N,N</i> -Dimethylaniline             | *                        |
| 2,5-Dimethylanisole                     | *                        |
| <i>N,N</i> -Dimethylbenzylamine         | *                        |
| 1,3-Dimethyl butylacetate               | *                        |
| Dimethylcyclohexylamine                 | 5–60 ppm                 |
| Dimethylethanolamine                    | 5–60 ppm                 |
| Dimethylether                           | *                        |
| Dimethylethylamine                      | 0.2–2 ppm                |
|                                         | 5–60 ppm                 |
| Dimethylformamide                       | 100–400 ppm              |
| 2,6-Dimethylheptane-4-one               | *                        |
| 2,4-Dimethyl hexane                     | *                        |
| 3,3-Dimethyl hexane                     | *                        |
| 1,1-Dimethyl hydrazine                  | 0.25–3 ppm               |
|                                         | 5–70 ppm                 |
| Dimethylisopropylamine                  | 15–70 ppm                |
| <i>N,N'</i> -Dimethylpiperazine         | *                        |
| Dimethyl sulphate                       | 0.005–0.05 ppm           |
| Dimethyl sulphide                       | 1–15 ppm                 |
| 4,7-Dimethylundecane                    | *                        |
| 1,4-Dioxane                             | 12.5–175 ppm             |



Table 10.18(a) Cont'd

| <i>Substance</i>                       | <i>Measuring range</i>   |
|----------------------------------------|--------------------------|
| 1,3-Dioxolan                           | *                        |
| Dipentene                              | *                        |
| Dipropylamine                          | *                        |
| Dipropylether                          | 100–4000 ppm             |
| Dipropylglycol methyl ether            | *                        |
| Di-sec octyl phthalate                 | 10–20 mg/m <sup>3</sup>  |
| Disulphoton                            | *                        |
| Dodecane                               | 50–400 ppm               |
| Dodecene                               | *                        |
| Epichlorohydrin                        | 5–50 ppm                 |
| 2,3-Epoxy-1-chloropropane              | *                        |
| 1,2-Epoxypropane                       | *                        |
| Ethanethiol                            | 0.1–20 ppm               |
| Ethanol (ethyl alcohol)                | 25–2000 ppm              |
|                                        | 100–3000 ppm             |
|                                        | 0.5–5.2 vol %            |
| Ethanolamine                           | 0.5–6 ppm                |
| Ether                                  | 100–4000 ppm             |
| 2-Ethoxyethanol                        | *                        |
| 2-Ethoxyethyl acetate                  | 50–700 ppm               |
| Ethyl acetate                          | 200–3000 ppm             |
| Ethyl acrylate                         | 5–300 ppm                |
| Ethylamine                             | 5–60 ppm                 |
| Ethylamyl ketone                       | *                        |
| Ethyl benzene                          | 5–300 ppm                |
|                                        | 30–600 ppm               |
| Ethyl bromide                          | 20–200 ppm               |
|                                        | 40–400 ppm               |
| Ethyl bromoacetate                     | *                        |
| Ethyl chloride                         | 5–50 ppm                 |
| Ethylene                               | 0.1–5 ppm                |
|                                        | 50–2500 ppm              |
|                                        | 0.5–2 vol %              |
| Ethylene bromide                       | 5–50 ppm                 |
| Ethylene chlorohydrin                  | *                        |
| Ethylene diamine                       | 0.5–12 ppm               |
| Ethylene dibromide                     | 1–50 ppm                 |
|                                        | 5–50 ppm                 |
| Ethylene glycol                        | 10–180 mg/m <sup>3</sup> |
| Ethylene glycol dimethyl ether         | 50–500 ppm               |
| Ethylene glycol dinitrate              | *                        |
| Ethylene glycol monobutylether         | *                        |
| Ethylene glycol monoethylether         | *                        |
| Ethylene glycol monoethylether acetate | 50–700 ppm               |
| Ethylene glycol monomethylether        | *                        |
| Ethyleneimine                          | *                        |
| Ethylene oxide                         | 1–15 ppm                 |
|                                        | 25–500 ppm               |
| Ethyl ether                            | 100–4000 ppm             |
| Ethyl formate                          | *                        |
| Ethyl glycol                           | *                        |
| Ethyl glycol acetate                   | 50–700 ppm               |
| 2-Ethyl-1-hexanol                      | *                        |
| Ethyl hexylacrylate                    | *                        |
| 2-Ethylhexylamine                      | *                        |
| Ethylidene dicycloheptene              | *                        |
| Ethyl lactate                          | *                        |

Table 10.18(a) Cont'd

| <i>Substance</i>                  | <i>Measuring range</i> |
|-----------------------------------|------------------------|
| Ethyl mercaptan                   | 0.1–20 ppm             |
| Ethyl methacrylate                | *                      |
| Ethyl morpholine                  | *                      |
| Ethyl vinyl ether                 | 20–300 ppm             |
| Exxsol D40                        | *                      |
| Fenthion                          | *                      |
| Fluorine                          | 0.1–2 ppm              |
| Fluorodichloromethane             | *                      |
| Formaldehyde                      | 0.04–25 ppm            |
|                                   | 2–40 ppm               |
| Formic acid                       | 1–15 ppm               |
| Furfural                          | *                      |
| Furfuryl alcohol                  | *                      |
| Furfurylamine                     | *                      |
| Gasoline                          | *                      |
| Glycerol trinitrate               | *                      |
| Glycidol                          | *                      |
| Glycol dinitrate                  | *                      |
| Heptane                           | 7–2100 ppm             |
|                                   | 200–600 ppm            |
|                                   | 500–1000 ppm           |
| 2-Heptanone                       | *                      |
| Heptene                           | 10–1000 ppm            |
| 1,2,3,4,4-hexachlor-1,3-butadiene | *                      |
| Hexachlorocyclopentadiene         | 1–50 ppm               |
| Hexamethylene diamine             | *                      |
| Hexane                            | 5–150 ppm              |
|                                   | 100–3000 ppm           |
| Hexene                            | 5–60 ppm               |
| Hexone                            | 1300–15 600 ppm        |
| sec-Hexyl acetate                 | *                      |
| Hexylene glycol                   | *                      |
| Hydrazine                         | 0.05–0.6 ppm           |
|                                   | 0.1–10 ppm             |
| Hydrobromic acid                  | 0.5–10 ppm             |
| Hydrocarbons (general)            | 0.1–1.3 vol %          |
|                                   | 2–28 mg/l              |
| Hydrochloric acid                 | 1–20 ppm               |
|                                   | 50–5000 ppm            |
| Hydrocyanic acid                  | 2–150 ppm              |
| Hydrofluoric acid                 | 1.5–60 ppm             |
| Hydrogen                          | 0.2–2 vol %            |
|                                   | 0.5–3 vol %            |
| Hydrogen bromide                  | *                      |
| Hydrogen peroxide                 | 0.1–3 ppm              |
| Hydrogen sulphide                 | 0.02–6 ppm             |
|                                   | 0.05–150 ppm           |
|                                   | 0.2–5 ppm              |
|                                   | 0.2–16 ppm             |
|                                   | 1–60 ppm               |
|                                   | 1–200 ppm              |
|                                   | 5–600 ppm              |
|                                   | 100–2000 ppm           |
|                                   | 0.2–7 vol %            |
|                                   | 2–40 vol %             |
| Iron pentacarbonyl                | *                      |
| Isoamyl alcohol                   | *                      |

Table 10.18(a) Cont'd

| <i>Substance</i>               | <i>Measuring range</i>   |
|--------------------------------|--------------------------|
| Isobutyl acetate               | *                        |
| Isobutyl acrylate              | *                        |
| Isooctyl nitrate               | *                        |
| Isopar G                       | 150–1000 ppm             |
| Isopentane                     | 10–50 ppm                |
| Isoprene                       | 10–30 ppm                |
| Isopropanol                    | 15–40 ppm                |
|                                | 50–4000 ppm              |
|                                | 100–3000 ppm             |
| Isopropenyl benzene            | 10–50 ppm                |
| Isopropyl acetate              | 200–3000 ppm             |
| Isopropylamine                 | 2–30 ppm                 |
|                                | 5–60 ppm                 |
| Isopropyl ether                | 100–4000 ppm             |
| Isopropylnitrate               | *                        |
| Kerosene                       | *                        |
| Limonene                       | *                        |
| Mercaptans (general)           | 0.5–5 ppm                |
|                                | 20–1000 ppm              |
| Mercury                        | 0.01–2 mg/m <sup>3</sup> |
| Mesityl oxide                  | 25–500 ppm               |
| Mesitylene                     | 10–100 ppm               |
| Methacrylic acid               | 1–15 ppm                 |
| Methane thiol                  | 0.1–20 ppm               |
| Methane                        | *                        |
| Methanol                       | 25–5000 ppm              |
|                                | 100–3000 ppm             |
| 2-Methoxyethanol               | *                        |
| 2-Methoxyethyl acetate         | *                        |
| 1-Methoxy-2-propanol           | 50–200 ppm               |
| 2-Methoxy-1-propanol           | *                        |
| 1-Methoxy-2-propylacetate      | 50–200 ppm               |
| 2-Methoxy-1-propylacetate      | *                        |
| Methoxypropylamine             | *                        |
| Methoxy propoxy propanol       | *                        |
| Methyl acetate                 | 200–3000 ppm             |
| Methyl acetylene               | *                        |
| Methyl acrylate                | 5–200 ppm                |
| Methyl allyl chloride          | *                        |
| Methylamine                    | 5–60 ppm                 |
| 2-Methylaminoethanol           | *                        |
| Methyl- <i>n</i> -amyl ketone  | *                        |
| Methylated spirits             | *                        |
| Methyl bromide                 | 3–100 ppm                |
|                                | 5–50 ppm                 |
| Methyl cellosolve              | *                        |
| Methyl cellosolve acetate      | *                        |
| Methyl chloroacetate           | *                        |
| Methyl chloroform              | 10–600 ppm               |
| Methyl cyclohexane             | 200–3000 ppm             |
| 2-Methyl cyclohexane-2-one     | *                        |
| Methyl cyclopentane            | *                        |
| <i>N</i> -Methyldiethanolamine | *                        |
| <i>N</i> -Methyldiethylamine   | 5–60 ppm                 |
| Methylene chloride             | 10–2000 ppm              |
| Methyl ethyl ketone            | 100–12 000 ppm           |
| Methyl ethyl sulphide          | *                        |

Table 10.18(a) Cont'd

| <i>Substance</i>                     | <i>Measuring range</i>   |
|--------------------------------------|--------------------------|
| Methyl formate                       | *                        |
| Methyl glycol                        | *                        |
| Methyl glycol acetate                | *                        |
| Methyl heptanone                     | *                        |
| Methyl iodide                        | *                        |
| Methyl isobutylketone                | 130–15 600 ppm           |
| Methyl mercaptan                     | 0.1–20 ppm               |
|                                      | 2–1000 ppm               |
| Methyl methacrylate                  | 15–700 ppm               |
| <i>n</i> -Methyl morpholine          | *                        |
| 1-Methylpropanol                     | *                        |
| 2-Methylpropan-2-ol                  | 50–500 ppm               |
| Methyl propyl ketone                 | 130–15 600 ppm           |
| <i>N</i> -Methylpyrrolidone          | *                        |
| $\alpha$ -Methyl styrene             | 10–50 ppm                |
| Methyl styrene                       | 10–100 ppm               |
| Methyl- <i>tert</i> -butylether      | *                        |
| Methyl vinyl ketone                  | *                        |
| Morpholine                           | *                        |
| Naphthalene                          | *                        |
| Natural gas                          | *                        |
| Nickel carbonyl                      | 0.1–1 ppm                |
| Nickel chloride                      | 0.1–1 mg/m <sup>3</sup>  |
| Nickel tetracarbonyl                 | 0.1–1 ppm                |
| Nitric acid                          | 1–50 ppm                 |
| Nitroglycerine                       | *                        |
| Nitrogen dioxide                     | 0.5–25 ppm               |
|                                      | 2–100 ppm                |
| Nitroglycol                          | *                        |
| 2-Nitropropane                       | *                        |
| Nitrous fumes                        | 0.025–10 ppm             |
|                                      | 2–150 ppm                |
|                                      | 20–500 ppm               |
|                                      | 50–2000 ppm              |
|                                      | 100–5000 ppm             |
| <i>n</i> -Nonane                     | 12–360 ppm               |
|                                      | 500–1000 ppm             |
| iso-Octane                           | 10–200 ppm               |
|                                      | 10–1500 ppm              |
| <i>n</i> -Octane                     | 1–300 ppm                |
|                                      | 10–2500 ppm              |
| Octene                               | 20–1000 ppm              |
| Oil                                  | 1–10 mg/m <sup>3</sup>   |
|                                      | 2.5–10 mg/m <sup>3</sup> |
| Oil (mist and vapour)                | 2.5–10 mg/m <sup>3</sup> |
| Olefins (general)                    | 1–55 mg/l                |
| Organic arsenic compounds and arsine | *                        |
| Organic basic nitrogen compounds     | *                        |
| Oxirane                              | 1–15 ppm                 |
|                                      | 25–500 ppm               |
| Oxygen                               | 5–23 vol %               |
| Ozone                                | 0.05–1.4 ppm             |
|                                      | 10–300 ppm               |
| 2,4-Pentadione                       | *                        |
| Pentane                              | 100–1500 ppm             |
| Pentan-2-one                         | 130–15 600 ppm           |
| Pentyl acetate                       | 200–1000 ppm             |

Table 10.18(a) Cont'd

| <i>Substance</i>                       | <i>Measuring range</i>                                                                     |
|----------------------------------------|--------------------------------------------------------------------------------------------|
| Perchloroethylene                      | 0.1–4 ppm<br>0.7–300 ppm<br>10–500 ppm                                                     |
| Petroleum hydrocarbons (general)       | 10–300 ppm<br>100–2500 ppm                                                                 |
| Phenol                                 | 1–20 ppm                                                                                   |
| Phenylhydrazine                        | *                                                                                          |
| Phenyl mercaptan                       | 2–100 ppm                                                                                  |
| Phosgene                               | 0.02–1 ppm<br>0.25–25 ppm                                                                  |
| Phosphine                              | 0.01–1 ppm<br>0.1–40 ppm<br>1–100 ppm<br>25–10 000 ppm<br>15–3000 ppm                      |
| Phosphoric acid ester                  | 0.05 ppm                                                                                   |
| $\alpha$ -Pinene                       | 10–200 ppm                                                                                 |
| Polytest                               | *                                                                                          |
| Potassium dichromate                   | *                                                                                          |
| Propanal                               | *                                                                                          |
| Propane                                | 0.5–1.3 vol %                                                                              |
| Propan-1-ol                            | 100–3000 ppm                                                                               |
| Propan-2-ol                            | 15–40 ppm<br>50–4000 ppm<br>100–3000 ppm                                                   |
| Propargyl alcohol                      | *                                                                                          |
| Propionic acid                         | 1–15 ppm                                                                                   |
| <i>n</i> -Propyl benzene               | 5–300 ppm                                                                                  |
| Propylene glycol                       | *                                                                                          |
| Propylene oxide                        | 4–60 ppm<br>50–2000 ppm                                                                    |
| Pyridine                               | 5 ppm                                                                                      |
| Pyrrolidine                            | *                                                                                          |
| Shellsol                               | *                                                                                          |
| Sodium chromate                        | 0.1–0.5 mg/m <sup>3</sup>                                                                  |
| Strontium chromate                     | 0.2–1 mg/m <sup>3</sup>                                                                    |
| Styrene                                | 10–250 ppm<br>50–400 ppm                                                                   |
| Sulphur dioxide                        | 0.1–3 ppm<br>0.5–25 ppm<br>1–25 ppm<br>20–2000 ppm<br>50–8000 ppm<br>1–5 mg/m <sup>3</sup> |
| Sulphuric acid                         | *                                                                                          |
| Tar from brown coal                    | *                                                                                          |
| Tar vapours                            | *                                                                                          |
| Tetrabromoethane                       | *                                                                                          |
| 1,1,2,2-Tetrabromoethane               | 0.5–3 ppm                                                                                  |
| 1,1,2,2-Tetrachloro-1,2-difluoroethane | *                                                                                          |
| 1,1,1,2-Tetrachloro-2,2-difluoroethane | *                                                                                          |
| 1,1,2,2-Tetrachloroethane              | *                                                                                          |
| Tetrafluoroethane                      | *                                                                                          |
| Tetrafluoromethane                     | *                                                                                          |
| Tetrahydrofuran                        | *                                                                                          |
| Tetrahydrothiophene                    | 1–16 ppm                                                                                   |
| Thioether                              | *                                                                                          |
| Thionyl chloride                       | 1–30 ppm                                                                                   |

Table 10.18(a) Cont'd

| <i>Substance</i>                      | <i>Measuring range</i>                  |
|---------------------------------------|-----------------------------------------|
| Thiophene                             | *                                       |
| Toluene                               | 5–300 ppm<br>50–400 ppm<br>100–1800 ppm |
| Toluene diisocyanate                  | 0.02–0.2 ppm                            |
| <i>o</i> -Tolidine                    | 1–30 ppm                                |
| Tributylamine                         | 2.5–50 ppm                              |
| 1,2,4-Trichlorobenzene                | *                                       |
| Trichlorotoluene                      | *                                       |
| Trichloroethane                       | 50–600 ppm                              |
| Trichloroethylene                     | 2–250 ppm<br>50–500 ppm                 |
| Trichlorofluoromethane                | 100–1400 ppm                            |
| Trichloronitromethane                 | 1–15 ppm                                |
| 1,2,3-Trichloropropane                | *                                       |
| 1,1,2-Trichloro-1,2,2-trifluoroethane | *                                       |
| Triethylamine                         | 5–60 ppm                                |
| Triethylene diamine                   | *                                       |
| Triethylene tetratriamine             | *                                       |
| Trifluorobromomethane                 | *                                       |
| Trimethylamine                        | 0.25–3 ppm<br>5–60 ppm                  |
| Trimethyl benzene                     | 10–100 ppm                              |
| Trimethyl phosphate                   | *                                       |
| Turpentine oil                        | *                                       |
| Undecane                              | 10–200 ppm                              |
| Vinyl acetate                         | *                                       |
| Vinyl bromide                         | 0.7–300 ppm                             |
| Vinyl chloride                        | 0.5–30 ppm<br>1–50 ppm<br>100–3000 ppm  |
| Vinyl ethyl ether                     | 20–300 ppm                              |
| Vinylidene chloride                   | 2.5–25 ppm                              |
| Vinyl trimethoxy silane               | 100–1000 ppm                            |
| Water vapour                          | 0.05–1 mg/l<br>0.5–18 mg/l<br>1–40 mg/l |
| White spirit                          | 30–200 ppm<br>100–1600 ppm              |
| Xylene (all isomers)                  | 10–400 ppm                              |
| Zinc chromate                         | 0.2–1 mg/m <sup>3</sup>                 |

\* Consult with supplier.

**Table 10.18(b) Dräger tubes for long-term measurements – with pump**

| <i>Dräger tube</i>                                | <i>Range of measurement for<br/>maximum period of use</i> |
|---------------------------------------------------|-----------------------------------------------------------|
| Acetic acid 5/a-L                                 | 1.25–40 ppm<br>(4 hr)                                     |
| Acetone 500/a-L                                   | 63–10 000 ppm<br>(8 hr)                                   |
| Ammonia 10/a-L                                    | 2.5–100 ppm<br>(4 hr)                                     |
| Benzene 20/a-L                                    | 5–200 ppm<br>(4 hr)                                       |
| Carbon dioxide 1000/a-L                           | 250–6000 ppm<br>(4 hr)                                    |
| Carbon disulphide 10/a-L                          | 1.3–100 ppm<br>(8 hr)                                     |
| Carbon monoxide 10/a-L                            | 2.5–100 ppm<br>(4 hr)                                     |
| Carbon monoxide 50/a-L                            | 6.3–500 ppm<br>(8 hr)                                     |
| Chlorine 1/a-L                                    | 0.13–20 ppm<br>(8 hr)                                     |
| Ethanol 500/a-L                                   | 63–8000 ppm<br>(8 hr)                                     |
| Hydrocarbon 100/a-L                               | 25–3000 ppm<br>(4 hr)                                     |
| Hydrochloric acid 10/a-L                          | 1.3–50 ppm<br>(8 hr)                                      |
| Hydrocyanic acid 10/a-L                           | 1.3–120 ppm<br>(8 hr)                                     |
| Hydrogen sulphide 5/a-L                           | 0.63–60 ppm<br>(8 hr)                                     |
| Methylene chloride 50/a-L                         | 13–800 ppm<br>(4 hr)                                      |
| Nitrogen dioxide 10/a-L                           | 1.3–100 ppm<br>(8 hr)                                     |
| Oxides of nitrogen 5/a-L (NO + NO <sub>2</sub> )  | 1.3–50 ppm<br>(4 hr)                                      |
| Oxides of nitrogen 50/a-L (NO + NO <sub>2</sub> ) | 13–350 ppm<br>(2 hr)                                      |
| Perchloroethylene 50/a-L                          | 13–300 ppm<br>(4 hr)                                      |
| Sulphur dioxide 5/a-L                             | 1.25–50 ppm<br>(4 hr)                                     |
| Sulphur dioxide 2/a-L                             | 0.5–20 ppm<br>(4 hr)                                      |
| Toluene 200/a-L                                   | 25–4000 ppm<br>(8 hr)                                     |
| Trichloroethylene 10/a-L                          | 2.5–200 ppm<br>(4 hr)                                     |
| Vinyl chloride 10/a-L                             | 1–50 ppm<br>(10 hr)                                       |

**Table 10.18(c) Direct-indicating Dräger diffusion tubes – no pump required**

| <i>Substance</i>          | <i>Measuring range</i> | <i>Max. operating time (hours)</i> |
|---------------------------|------------------------|------------------------------------|
| Acetic acid 10/a-D        | 10–200 ppm × hr        | 8                                  |
| Ammonia 20/1-D            | 20–1500 ppm × hr       | 8                                  |
| Butadiene 10/a-D          | 10–300 ppm × hr        | 8                                  |
| Carbon dioxide 500/a-D    | 500–20 000 ppm × hr    | 8                                  |
| (1%/a-1)                  | 1–30 vol % × hr        | 360                                |
| Carbon monoxide 50/a-D    | 50–600 ppm × hr        | 360                                |
| Ethanol 1000/a-D          | 1000–25 000 ppm × hr   | 8                                  |
| Ethyl acetate 500/a-D     | 500–10 000 ppm × hr    | 8                                  |
| Hydrochloric acid 10/a-D  | 10–200 ppm × hr        | 8                                  |
| Hydrocyanic acid 20/a-D   | 20–200 ppm × hr        | 8                                  |
| Hydrogen sulphide 10/a-D  | 10–300 ppm × hr        | 72                                 |
| Nitrogen dioxide 10/a-D   | 10–2000 ppm × hr       | 24                                 |
| Olefines 100/a-D          | 100–2000 ppm × hr      | 8                                  |
| Perchloroethylene 200/a-D | 200–1500 ppm × hr      | 8                                  |
| Sulphur dioxide 5/a-D     | 5–150 ppm × hr         | 10                                 |
| Toluene 100/a-D           | 100–3000 ppm × hr      | 8                                  |
| Trichloroethylene 200/a-D | 200–1000 ppm × hr      | 8                                  |
| Water vapour 5/a-D        | 5–100 mg/l × hr        | 8                                  |

**Table 10.19 Selected sources of inaccuracy in use of colour detector tubes**

|                                                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Failure to break both ends of the sealed tube before insertion of the tube into the pump housing.                                                                                                                                                                           |
| Insertion of the tube incorrectly into the pump housing (the correct direction is indicated on the tube).                                                                                                                                                                   |
| Reuse of previously used tubes. It is advisable not to reuse tubes even if previous use indicated zero.                                                                                                                                                                     |
| Leaks in sample lines, or insufficient time allowed to lapse between pump strokes when extensions are used.                                                                                                                                                                 |
| Use of tubes beyond expiry of the shelf-life. Tubes should be stored under refrigerated conditions but allowed to warm to ambient temperature prior to use.                                                                                                                 |
| III-defined stain format because it is irregular, diffuse or has failed, i.e. not at right angles to tube wall. (This can be caused by poor quality of granular support medium used by manufacturer.) It is advisable to read the maximum value indicated.                  |
| Use of tubes under conditions of temperature, pressure or humidity outside the range of calibration.                                                                                                                                                                        |
| Blockages or faulty pumps. Pumps should be checked periodically as instructed by the manufacturer. They can be calibrated using rotameters or bubble flowmeters. Unless pumps possess a limiting orifice they should be calibrated with the air indicator tube in position. |
| Misuse of the pump, e.g. incomplete stroke or wrong number of strokes.                                                                                                                                                                                                      |
| Mismatch of tubes with type of pump.                                                                                                                                                                                                                                        |
| Interference due to the presence of other contaminants capable of reacting with the tube reagent. This can result in over- or under-estimation of concentrations. The former is the more likely and hence errs on the side of safety.                                       |
| Tube blockage caused by airborne dusts, affecting the flow rate.                                                                                                                                                                                                            |

**Table 10.20 Examples of chemicals for which paper-tape colorimetric instruments are available**

|                   |                             |
|-------------------|-----------------------------|
| Ammonia           | Hydrogen selenide           |
| Arsine            | Hydrogen sulphide           |
| Chlorine          | Isocyanates                 |
| Diborane          | Nitrogen dioxide            |
| Germane           | <i>p</i> -Phenylene diamine |
| Hydrazines        | Phosgene                    |
| Hydrogen chloride | Phosphine                   |
| Hydrogen cyanide  | Silane                      |
| Hydrogen fluoride | Sulphur dioxide             |



**Table 10.21 Considerations when using instruments with catalytic detection**


---

|                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------|
| Portable instrument should be of explosion-proof design; fixed point systems may rely on remote sensing heads             |
| For zero adjustment, place instrument in uncontaminated air or use activated charcoal filters to remove flammable vapours |
| Sources of error include:                                                                                                 |
| Inadequate calibration                                                                                                    |
| Drift due to age                                                                                                          |
| Design not fail-safe (i.e. no indication of component failure)                                                            |
| Poisoning of Pellistor by, e.g., silicones, halocarbons, leaded petrol                                                    |
| Too high a sampling rate (causing cooling of the elements)                                                                |
| Sampling lines and couplings not airtight                                                                                 |
| Condensation of high-boiling-point components in the line between sample head and sensor                                  |
| Hostile environment                                                                                                       |

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particles of respirable dimensions from non-respirable fractions include horizontal elutriation and centrifugation. Equipment for personal monitoring comprises a lapel-mounted filter holder connected to a portable pump with a flow rate of about 3 litres/min. Respirable matter can be separated by use of a small cyclone. In order to ensure uniformity of fractionation, smooth and constant flow rates are essential. The dust collection and analytical stages are separate operations. For background monitoring, miniaturization is unimportant and as a consequence equipment incorporates pumps of higher flow rates, typically  $\leq 100$  l/min. This enables sampling times to be short and larger samples to be obtained (e.g. for laboratory analysis). Both direct-reading and absolute methods are available.

The main principles of instrument design are summarized in Table 10.23. In filtration, e.g. for gravimetric analysis, selection of filter material (Table 10.22) requires careful consideration in terms of application, strength, collection efficiency, compatibility with pump, water uptake, etc. Humidity-controlled balance rooms, microbalances and careful handling techniques may be required.

**Table 10.22 Examples of filter material for collection of particulates**


---

| <i>Filter Material</i>                | <i>Application</i>                                                                                                    | <i>Characteristics</i>                                                                              |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| Cellulose                             | Washing of samples to determine water soluble fraction or for ashing to determine organic content                     | High flowrates, low pressure drop, low impurity levels                                              |
| Glass fibre                           | High-flow samplers for gravimetric assessment                                                                         | High efficiencies, high flowrates, high wet strength, good temperature stability, low pressure drop |
| Mixed celluloses, e.g. nitrate, ester | Microscopy (asbestos); metal content (by atomic absorption, atomic emission, fluorescence and infra-red spectrometry) | Low levels of metal impurities; oxidizable during digestion                                         |
| Polycarbonate                         | Optical microscopy; organic content                                                                                   | Transparent grades available, non-hygroscopic, low ash content, solvent resistant                   |
| PTFE                                  | Sampling for HPLC or UV analysis. PAHs                                                                                | Inert, hydrophobic                                                                                  |
| PVC                                   | Gravimetric analysis, carbon black, quartz, silica                                                                    | Acid and alkali resistant; low water pick-up                                                        |
| Silver membrane                       | Crystalline materials for X-ray diffraction                                                                           | Costly. High collection efficiency. Uniform pore size                                               |

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**Table 10.23 Particulates monitoring – principles of apparatus**

| <i>Principle</i>                       | <i>Examples</i>                    | <i>Collection</i>                                     | <i>Sampling rate<br/>(l/min)</i> | <i>Collection efficiency<br/>(%)</i>                                           | <i>Analysis</i>                                 | <i>Advantages/disadvantages</i>                                                                                                                                  |
|----------------------------------------|------------------------------------|-------------------------------------------------------|----------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Impinger                               | Midget impinger                    | By bubbling through liquid phase                      |                                  |                                                                                | Microscopy                                      | Aggregates broken up; only particles >1 µm collected. In wet impingers particles must be water insoluble.                                                        |
| Impactor                               | 1. Konimeter                       | Impaction on gel-coated disc                          | 1–37<br>(depending on type)      | 60–100                                                                         | Built-in microscope<br>Microscopy               | Underestimates small particles, overestimates large particles. Particles between 0.5 and 5.0 µm collected.                                                       |
|                                        | 2. Cascade impactor                | Impaction on 4 stages on glass disc                   |                                  |                                                                                |                                                 |                                                                                                                                                                  |
|                                        | 3. Andersen sampler                | Impaction in 8 stages onto glass or metal discs       |                                  |                                                                                |                                                 |                                                                                                                                                                  |
| Electrostatic or thermal precipitation | Casella thermal precipitator       | Deposition on glass slides or discs                   | 1–85                             | 90–100                                                                         | Microscopy                                      | Instrument inflexible. Poor for large particles. Collection efficiency increases as particle size decreases.                                                     |
| Filtration                             | 1. Fibrous filter                  |                                                       | 1–50                             | 85–100<br>Depends on particle size values stated for those usually encountered | Gravimetric or chemical                         | Fibrous filter good for gravimetric analysis for a range of particle sizes (fast and relatively easy).                                                           |
|                                        | 2. Membrane filter                 |                                                       |                                  |                                                                                | Microscopy, gravimetric or chemical             |                                                                                                                                                                  |
| Respirable dust separation             | 1. Hexhlet (horizontal elutriator) | Fibrous filter                                        | 1–50                             | 60–100                                                                         | Gravimetric or chemical                         | Instrument must be kept horizontal for sampling; relatively large quantities of dust collected in short period.                                                  |
|                                        | 2. Casella cyclone                 | Fibrous or membrane filter                            |                                  |                                                                                | Gravimetric, microscopy or chemical             | The only instrument for carrying out personal respirable dust sampling.                                                                                          |
|                                        | 3. Anderson sampler                | Selective inlet 2 dust fractions (<10 µm and <2.5 µm) | 16.7                             |                                                                                | Gravimetric                                     | Can be used for unattended operations                                                                                                                            |
| Beta attenuation                       |                                    | Impaction on disc or filtration                       |                                  |                                                                                | Attenuation of beta radiation<br>Direct reading | Provides short- or long-term TWA (e.g. up to 8 hr, depending on model) of dust or fume mass concentration. Suitable for unattended automated continuous methods. |

**Table 10.23 Cont'd**

| <i>Principle</i> | <i>Examples</i>                        | <i>Collection</i>                                  | <i>Sampling rate<br/>(l/min)</i> | <i>Collection efficiency<br/>(%)</i> | <i>Analysis</i>                                           | <i>Advantages/disadvantages</i>                                                                                                                              |
|------------------|----------------------------------------|----------------------------------------------------|----------------------------------|--------------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Photometry       | 1. Number concentration,<br>e.g. Royco |                                                    |                                  |                                      | Light scattered on to a photomultiplier<br>Direct reading | Gives automatic particle sizing but accuracy only guaranteed if calibrated for particulate of interest.                                                      |
|                  | 2. Mass concentration<br>e.g. Simslin  |                                                    |                                  |                                      | Light scattered onto a photomultiplier<br>Direct reading  | Very versatile – only accurate continuous long-term mass monitoring instrument; sample may also be collected on a filter. Suitable for automated operations. |
| Piezoelectric    |                                        | Electrostatic frequency of crystal. Direct reading |                                  |                                      | Change in resonant frequency                              | Unsuitable for ambient air monitoring.                                                                                                                       |

## Official methods

Regulatory and advisory bodies publish methods for *ambient* air analysis such as those issued by the British Standards Institute and the US Environment Protection Agency (Tables 10.24 and 10.25, respectively). Methods for assessment of *workplace* air are published by the Health and Safety Executive. Some of these are generic methods (Table 10.26) whilst others are compound specific (Table 10.27). Examples of other official methods for monitoring workplace air quality are those published by the British Standards Institute (Table 10.28), and the US National Institute of Occupational Safety and Health (Table 10.29). Table 10.30 provides additional guidance on analytical techniques for a selection of substances.

**Table 10.24** Selected British Standards relating to ambient air pollution measurements

| <i>British Standard</i> | <i>Subject</i>                                          | <i>Method</i>                                                   |
|-------------------------|---------------------------------------------------------|-----------------------------------------------------------------|
| BS 893                  | Particulate matter in ducts                             |                                                                 |
| BS 1747                 | Deposit gauges                                          |                                                                 |
|                         | Particulate matter                                      |                                                                 |
|                         | Sulphur dioxide                                         | Thorin spectrophotometry                                        |
|                         | Directional dust gauges                                 |                                                                 |
|                         | Sampling equipment for determination of gaseous sulphur |                                                                 |
|                         | Nitrogen dioxide in ambient air                         | Modified Griess–Salzman method                                  |
|                         | Nitrogen oxides in ambient air                          | Chemiluminescence                                               |
|                         | Sulphur dioxide in ambient air                          | Tetrachloromercurate/pararosaline                               |
|                         | Black smoke index in ambient air                        |                                                                 |
|                         | Ozone                                                   | Chemiluminescence                                               |
|                         | Particulate lead in aerosol                             | Collected on filter with atomic absorption spectrometry         |
|                         |                                                         | General methods                                                 |
| BS 1756                 | Flue gases                                              |                                                                 |
| BS 2811, 2742           | Smoke monitoring                                        |                                                                 |
| BS 3048                 | Flue gases                                              | Continuous and automatic                                        |
| BS 3405                 | Particulate matter including grit and dust              |                                                                 |
| BS 3406                 | Particle size distribution                              | Various including microscopy                                    |
| BS 4995                 | Gas mixtures                                            | Preparation                                                     |
| BS 5243                 | Airborne radioactive gases and particulates             | Various                                                         |
| BS 5343                 | Long-term gas detector tubes                            |                                                                 |
| BS ISO 6768             | Nitrogen dioxide                                        | Modified Griess–Salzman                                         |
| BS ISO 10312            | Asbestos                                                | Direct-transfer transmission                                    |
|                         |                                                         | Electron microscopy                                             |
| BS ISO 10498            | Sulphur dioxide                                         | Ultra-violet fluorescence                                       |
| BS ISO 10473            | Particulate mass on filters                             | Beta-ray absorption                                             |
| BS ISO 12884            | Polycyclic aromatic hydrocarbons                        | Collection of filters with gas chromatography/mass spectrometry |
| BS ISO 13794            | Asbestos                                                | Indirect-transfer transmission                                  |
|                         |                                                         | Electron microscopy                                             |
| BS ISO 13964            | Ozone                                                   | Ultra-violet photometry                                         |
| BS ISO 14965            | Non-methane organics                                    | Flame ionization                                                |
| BS ISO 16000            | Indoor formaldehyde and other carbonyl compounds        | Active and diffusive sampling                                   |
| BS EN 12341             | Suspended matter                                        | Reference and field methods                                     |
| BS EN 13528             | Gases and vapours                                       | Diffusive samplers                                              |

**Table 10.25 Selected EPA standard methods for air monitoring (Code of Federal register-protection of the environment section, 40)**

| <i>Subject</i>                                                                                       | <i>Method reference (see original reference)</i> |
|------------------------------------------------------------------------------------------------------|--------------------------------------------------|
| <b>Part 60 Appendix A</b>                                                                            |                                                  |
| Various measurement techniques for sample and velocity from stationary sources, stacks, ducts, pipes | 1, 1A, 2, 2A, 2B, 2C                             |
| CO <sub>2</sub> oxygen, excess air, dry molecular weight                                             | 3                                                |
| O <sub>2</sub> and CO <sub>2</sub>                                                                   | 3A                                               |
| Moisture from stacks                                                                                 | 4                                                |
| Particulate                                                                                          | 5                                                |
| – stationary sources                                                                                 | 5A                                               |
| – asphalt                                                                                            | 5B                                               |
| – non-sulphuric acid matter                                                                          | 5D                                               |
| – from positive pressure fabric filters                                                              | 5E                                               |
| – wool fibre-glass                                                                                   | 5F                                               |
| – non-sulphate matter                                                                                | 5G                                               |
| – wood heaters                                                                                       | 5H                                               |
| – in-stack filtration method                                                                         | 17                                               |
| SO <sub>2</sub> from stationary sources                                                              | 6                                                |
| – fossil fuel                                                                                        | 6A, 6B                                           |
| – stationary sources                                                                                 | 6C                                               |
| NO <sub>x</sub> from stationary sources                                                              | 7 (various methods 7A–7E)                        |
| Sulphuric acid mist and SO <sub>2</sub> from stationary sources                                      | 8                                                |
| Visual opacity                                                                                       | 9                                                |
| CO from stationary sources                                                                           | 10, 10A, 10B                                     |
| H <sub>2</sub> S (refineries)                                                                        | 11                                               |
| Inorganic lead                                                                                       | 12                                               |
| Total fluoride                                                                                       | 13A, 13B                                         |
| Fluoride (aluminium plants)                                                                          | 14                                               |
| H <sub>2</sub> S, COS, CS <sub>2</sub>                                                               | 15                                               |
| Total reduced sulphur (sulphur recovery plants)                                                      | 15A                                              |
| Sulphur                                                                                              | 16                                               |
| Total reduced sulphur (stationary sources)                                                           | 16A, 16B                                         |
| Gaseous organics                                                                                     | 18                                               |
| SO <sub>2</sub> , particulates and NO <sub>x</sub> emission rates                                    | 19, 20                                           |
| Volatile organic leaks                                                                               | 21                                               |
| Visual assessment of fugitive emissions from material sources and smoke from flares                  | 22                                               |
| Chlorinated dioxins and dibenzofurans                                                                | 23                                               |
| Volatile content, water, density, volume and weight of surface coatings                              | 24, 24A                                          |
| Total gaseous organics                                                                               | 25, 25A, 25B                                     |
| HCl                                                                                                  | 26                                               |
| Vapour tightness of gasoline delivery tanks                                                          | 27                                               |
| <b>Part 61 Appendix B (Hazardous air pollutants)</b>                                                 |                                                  |
| Particulate and gaseous Hg                                                                           | 101, 101A, 102                                   |
| Beryllium                                                                                            | 103, 104                                         |
| Vinyl chloride                                                                                       | 106                                              |
| Gaseous and particulate arsenic                                                                      | 108                                              |
| Benzene                                                                                              | 110                                              |
| Polonium-210                                                                                         | 111                                              |
| Radionuclide                                                                                         | 114                                              |
| Radon-222                                                                                            | 115                                              |

**Table 10.26 HSE generic techniques for monitoring quality of workplace air**

| <i>Subject</i>                                                                             | <i>MDHS number</i> |
|--------------------------------------------------------------------------------------------|--------------------|
| Generation of test atmospheres of organic vapours by the syringe injection technique       | 3                  |
| Generation of test atmospheres of organic vapours by the permeation tube method            | 4                  |
| On-site validation of sampling methods                                                     | 5                  |
| General methods for sampling and gravimetric analysis of respirable and inhalable dust     | 14/3               |
| Protocol for assessing the performance of a diffusive sampler                              | 27                 |
| Sorbent tube standards preparation by the syringe injection technique                      | 33/2               |
| Protocol for assessing the performance of a pumped sampler for gases and vapours           | 54                 |
| General methods for sampling airborne gases and vapours                                    | 70                 |
| Analytical quality in workplace air monitoring                                             | 71                 |
| Measurement of air change rates in factories and offices                                   | 73                 |
| Dustiness of powders and materials                                                         | 81                 |
| The dust lamp                                                                              | 82                 |
| Discrimination between fibre types in samples of airborne dust on filters using microscopy | 87                 |

## Sampling strategies

The results of environmental monitoring exercises will be influenced by a variety of variables including the objectives of the study, the sampling regime, the technical methods adopted, the calibre of staff involved, etc. Detailed advice about sampling protocols (e.g. where and when to sample, the volume and number of samples to collect, the use of replicates, controls, statistical interpretation of data, etc.) and of individual analytical techniques are beyond the scope of this book. Some basic considerations include the following, with examples of application for employee exposure and incident investigation.

### *Sampling*

It is crucial to consider the sampling protocol, equipment, calibration, and validation. Tightly sealed sample containers of adequate strength, and generally protected from heat and light, are required. Extreme care must be taken with sample identification and labelling. Sample containers must not become contaminated with the substance under study or by any major interfering chemicals. Precautions must also prevent accidental loss of material collected awaiting analysis, e.g. during storage or transport. For example, water samples can become affected by evaporation, degassing, chemical degradation, photophysical degradation, precipitation, or damage of suspended matter.

Samples must be representative of the environment in relation to study objectives and to permit comparison of data with appropriate standards, i.e. average concentrations, time-weighted exposures, peak concentrations, etc. Replicate samples may be advisable.

### *Methods*

Consideration must be given to equipment calibration and method suitability in terms of sensitivity, limits of detection, accuracy, precision, repeatability.

**Table 10.27 HSE methods for measuring levels of specific airborne chemicals**

| <i>Substance</i>                                           | <i>Method</i>                                                                                                     | <i>MDHS number</i> |
|------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|--------------------|
| Acrylamide in air                                          | Lab method with high performance liquid chromatography after collection in an impinger containing water           | 57                 |
| Acrylonitrile in air                                       | Charcoal adsorption tube and gas chromatography                                                                   | 1                  |
|                                                            | Lab method using porous polymer adsorption tube and thermal desorption with gas chromatography                    | 2                  |
|                                                            | Lab method using porous polymer diffusive samplers with thermal desorption and gas chromatography                 | 55                 |
|                                                            | Lab method using pumped acid-coated filters, desorption and liquid chromatography                                 | 75                 |
| Aromatic amines in air and on surfaces                     | Lab method using glass-fibre/Tenax tube sampling and high performance liquid chromatography                       | 62                 |
| Aromatic carboxylic acid anhydrides in air                 | Field method using acid hydrolysis, diazotization, coupling and spectrophotometry                                 | 49                 |
| Aromatic isocyanates in air                                | Lab method using continuous flow or flow injection analysis hydride generation and atomic absorption spectrometry | 41/2               |
| Arsenic and inorganic compounds of arsenic (except arsine) | Colorimetric field method using silver diethyldithiocarbamate in presence of excess silver nitrate                | 34                 |
| Arsine in air                                              | Sampling and evaluation by phase-contrast microscopy                                                              | 39/4               |
| Asbestos fibres in air                                     | Sampling and identification by polarized light microscopy                                                         | 77                 |
| Asbestos in bulk material                                  | Lab method using high performance liquid chromatography                                                           | 92                 |
| Azodicarbonamide in air                                    | Charcoal adsorbent tubes, solvent desorption, and gas chromatography                                              | 17                 |
| Benzene in air                                             | Lab method using pumped porous polymer adsorbent tubes, thermal desorption and gas chromatography                 | 22                 |
|                                                            | Lab method using porous polymer diffusive samplers, thermal desorption and gas chromatography                     | 50                 |
|                                                            | Lab method using flame atomic absorption spectrometry or electrothermal atomic absorption spectrometry            | 29/2               |
|                                                            | Lab method using pumped molecular sieve sorbent tubes, thermal desorption and gas chromatography                  | 53                 |
| Beryllium and beryllium compounds in air                   | Lab method using molecular sieve samplers, thermal desorption and gas chromatography                              | 63                 |
|                                                            | Flame atomic adsorption or electrothermal atomic absorption spectrometry                                          | 12/2               |
| Cadmium and inorganic cadmium compounds in air             | Charcoal adsorbent tubes with solvent desorption and gas chromatography                                           | 15                 |

Table 10.27 Cont'd

| <i>Substance</i>                                                                              | <i>Method</i>                                                                                                                                                                                                             | <i>MDHS number</i> |
|-----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Chlorinated hydrocarbon solvent vapours in air                                                | Lab method using pumped charcoal adsorption tubes, solvent desorption and gas chromatography                                                                                                                              | 28                 |
| Chromium and inorganic compounds of chromium in air                                           | Flame atomic absorption spectrometry                                                                                                                                                                                      | 12/2               |
| Chromium (hexavalent) in chromium plating mists                                               | Colorimetric field method using 1,5-diphenylcarbazine                                                                                                                                                                     | 52/3               |
| Chromium (total and speciated chromium) in chromium plated mists                              | Colorimetric field method using 1,5-diphenyl carbazine after oxidation with silver (1)-catalysed peroxydisulphate                                                                                                         | 67                 |
| Coal tar pitch volatiles: measurement of particulates and cyclohexane soluble material in air | Lab method using filters and gravimetric analysis                                                                                                                                                                         | 68                 |
| Cobalt and cobalt compounds in air                                                            | Lab method using flame atomic absorption spectrometry                                                                                                                                                                     | 30/2               |
| Cristobalite in respirable airborne dust                                                      | Lab method using X-ray diffraction (direct method)                                                                                                                                                                        | 76                 |
| Diethyl sulphate and dimethyl sulphate                                                        | Lab method using Tenax sorbent tube, thermal desorption and gas chromatography with mass spectrometry                                                                                                                     | 89                 |
| Diocetyl phthalate                                                                            | Lab method using Tenax sorbent tubes, solvent desorption and gas chromatography                                                                                                                                           | 32                 |
| Ethylene dibromide                                                                            | Lab method with pumped Tenax absorbent tubes, solvent desorption and electron capture gas chromatography                                                                                                                  | 45                 |
| Ethylene oxide                                                                                | Lab method using charcoal absorbent tubers, solvent desorption and gas chromatography                                                                                                                                     | 26                 |
| Formaldehyde in air                                                                           | Lab method using diffusive sampler, solvent desorption and high performance liquid chromatography                                                                                                                         | 78                 |
| Glutaraldehyde in air                                                                         | Lab method using high performance liquid chromatography                                                                                                                                                                   | 93                 |
| Glycol ether and glycol ether acetate vapours in air                                          | Lab method using charcoal adsorbent tubes, solvent desorption and gas chromatography                                                                                                                                      | 21                 |
| Glycol ether and glycol acetate vapours in air                                                | Lab method using Tenax sorbent tubes, thermal desorption and gas chromatography                                                                                                                                           | 23                 |
| <i>n</i> -Hexane in air                                                                       | Lab method using charcoal diffusive samplers, solvent desorption and gas chromatography                                                                                                                                   | 74                 |
| Hydrazine in air                                                                              | Lab method using sampling either onto acid-coated glass-fibre filters followed by solvent desorption or into specially constructed impingers. Final analysis by derivatization and high performance liquid chromatography | 86                 |
| Hydrocarbons (mixed C <sub>3</sub> –C <sub>10</sub> )                                         | Lab method using pumped porous polymer and carbon sorbent tubes, thermal desorption and gas chromatography                                                                                                                | 60                 |
| Hydrocarbons (mixed C <sub>5</sub> –C <sub>10</sub> )                                         | Lab method using porous polymer diffusive samplers, thermal desorption and gas chromatography                                                                                                                             | 66                 |



Table 10.27 Cont'd

| <i>Substance</i>                                                                         | <i>Method</i>                                                                                                                                                               | <i>MDHS number</i> |
|------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Hydrogen cyanide in air                                                                  | Lab method using an ion-selective electrode                                                                                                                                 | 56/2               |
| Hydrogen fluoride and fluorides in air                                                   | Lab method using an ion-selective electrode or ion chromatography                                                                                                           | 35/2               |
| Lead and inorganic compounds of lead in air                                              | Lead method using flame or electrothermal atomic absorption spectrometry                                                                                                    | 6/3                |
|                                                                                          | Lab method using X-ray fluorescence spectrometry                                                                                                                            | 7                  |
|                                                                                          | Colorimetric field method                                                                                                                                                   | 8                  |
| Mercury vapour in air                                                                    | Diffusive samplers with qualitative on-site colorimetric analysis and quantitative cold vapour atomic absorption spectrometry in the laboratory                             | 59                 |
| Metals and metalloids in workplace air                                                   | X-ray fluorescence spectrometry                                                                                                                                             | 91                 |
| Metalworking fluids (water based)                                                        | Elemental marker method using flame atomic absorption spectrometry or inductively coupled plasma emission spectrometry                                                      | 95                 |
| Mineral oil mist from mineral oil-based metalworking fluids                              | Pumped filters with gravimetric determination                                                                                                                               | 84                 |
| Newspaper print rooms: measurement of total particulate and cyclohexane-soluble material | Lab method using filters and gravimetric evaluation                                                                                                                         | 48                 |
| Nickel and inorganic compounds of nickel in air (except nickel carbonyl)                 | Lab method using flame atomic absorption spectrometry or electrothermal atomic absorption spectrometry                                                                      | 42/2               |
| Organic isocyanates in air                                                               | Lab method with sampling either onto coated glass-fibre filters followed by solvent desorption, or into impingers and analysis using high performance liquid chromatography | 25/3               |
| Peroxodisulphate salts in air                                                            | Lab method using mobile phase ion chromatography                                                                                                                            | 79                 |
| Pesticides in air and on surfaces                                                        | Pumped filters/sorbent tubes with gas chromatography                                                                                                                        | 94                 |
| Platinum metal and soluble platinum compounds in air                                     | Lab method using electrothermal atomic absorption spectrometry or inductively coupled plasma mass spectrometry                                                              | 46/2               |
| Quartz in respirable airborne dusts                                                      | Lab method using infra-red spectroscopy (KBr disc technique)                                                                                                                | 38                 |
| Resin acids in rosin (colophony) solder flux fume                                        | Lab method using gas chromatography                                                                                                                                         | 83                 |
| Rubber fume in air measured as total particulate and cyclohexane-soluble material        | Lab method using filters and gravimetric estimation                                                                                                                         | 47/2               |
| Styrene in air                                                                           | Lab method using charcoal adsorbent tubes, solvent desorption and gas chromatography                                                                                        | 20                 |
|                                                                                          | Lab method using porous polymer adsorbent tubes, thermal desorption and gas chromatography                                                                                  | 31                 |

Table 10.27 Cont'd

| <i>Substance</i>                                                                   | <i>Method</i>                                                                                                                               | <i>MDHS number</i> |
|------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Tetra-alkyl lead compounds in air                                                  | Lab method using porous polymer diffusive samplers, thermal desorption and gas chromatography                                               | 43                 |
|                                                                                    | Lab method using charcoal diffusive samplers                                                                                                | 44                 |
|                                                                                    | Personal monitoring with atomic absorption analysis or electrothermal atomization or X-ray fluorescence spectrometry or on-site colorimetry | 9                  |
| Toluene in air                                                                     | Lab method using pumped charcoal adsorption tubes, solvent desorption and gas chromatography                                                | 36                 |
|                                                                                    | Lab method using pumped porous polymer adsorption tubes, thermal desorption and gas chromatography                                          | 40                 |
|                                                                                    | Lab method using charcoal diffusive samplers, solvent desorption and gas chromatography (using Drager ORSA monitor)                         | 64                 |
| Triglycidyl isocyanurate (and coating powders containing triglycidyl isocyanurate) | Lab method using charcoal diffusive samplers, solvent desorption and gas chromatography                                                     | 69                 |
|                                                                                    | Lab method using pumped filter, desorption and liquid chromatography                                                                        | 85                 |
| Vinyl chloride in air                                                              | Lab method using charcoal adsorbent tubes, solvent desorption and gas chromatography                                                        | 24                 |
| Volatile organic compounds in air                                                  | Lab method using pumped solid sorbent tubes, thermal desorption and gas chromatography                                                      | 72                 |
|                                                                                    | Lab method using diffusive solid sorbent tubes, thermal desorption and gas chromatography                                                   | 80                 |
|                                                                                    | Lab method using diffusive samplers, solvent desorption and gas chromatography                                                              | 88                 |
|                                                                                    | Lab method using pumped solid sorbent tubes, solvent desorption and gas chromatography                                                      | 96                 |
|                                                                                    |                                                                                                                                             |                    |

## Selected strategies for determining employees' exposure to airborne chemicals

The scheme in Figure 10.1 illustrates a general approach for devising a monitoring strategy. Where doubt exists about the level of exposure, a crude assessment can be made by determining levels under expected worst-case situations, paying attention to variations and possible errors. More detailed assessment may be required, depending upon the outcome. Sampling times should be long enough to overcome fluctuations but short enough for results to be meaningfully associated with specific activities and for corrective actions to be identified. For monitoring particulates, sampling times may be determined from the following equation:

$$\text{Minimum volume (m}^3\text{)} = \frac{10 \times \text{sensitivity of analytical method (mg)}}{\text{suitable hygiene standard (mg/m}^3\text{)}}$$

**Table 10.28 Selected British Standards for analysis of workplace air quality**

| <i>Standard</i> | <i>Subject</i>                                                                                                                         | <i>Method</i>                                            |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|
| BS 6069         | Vinyl chloride                                                                                                                         | Charcoal tube and gas chromatography                     |
|                 | Sulphur dioxide                                                                                                                        |                                                          |
|                 | Particulate lead and lead compounds                                                                                                    | Flame atomic absorption spectrometry                     |
|                 | Chlorinated hydrocarbon vapours                                                                                                        | Charcoal tube, solvent desorption and gas chromatography |
|                 | Aromatic hydrocarbon vapours                                                                                                           | Charcoal tube, solvent desorption and gas chromatography |
|                 | Asbestos                                                                                                                               | Fibre count                                              |
|                 | Particulates                                                                                                                           | Gravimetry                                               |
| BS 7384         | Arc welding particulates                                                                                                               | Various                                                  |
| BS EN 1231      | Short-term detector tubes                                                                                                              | Colorimetry                                              |
| BS EN 45544     | Electrical apparatus used for the detection and direct concentration measurement to toxic gases. General requirements and test methods | Various                                                  |
| BS 50054        | Electrical apparatus for the detection and measurement of combustible gases. General requirements and test methods                     | Various                                                  |
| BS EN 50104     | Electrical apparatus for the detection and measurement of oxygen. Performance requirements and test methods                            |                                                          |
| BS EN 61779     | Electrical apparatus for the detection of flammable gases. General requirements and test methods                                       |                                                          |
| BS EN 10882     | Welding fumes and gases                                                                                                                | Personal dosimetry                                       |
| BS ISO 11041    | Particulate arsenic and arsenic compounds and arsenic trioxide                                                                         | Hydride generation and atomic absorption spectrometry    |
| BS ISO 11174    | Particulate cadmium and cadmium compounds                                                                                              | Flame and electrothermal atomic absorption spectrometry  |
| BS ISO 15202    | Metals and metalloids in particulate matter                                                                                            | Inductively coupled plasma atomic emission spectrometry  |
| BS ISO 16107    | Evaluation of diffusive samplers                                                                                                       |                                                          |
| BS EN 838       | Diffusive samplers                                                                                                                     | Test methods                                             |
| BS EN 1076      | Pumped sorbent tubes                                                                                                                   | Test methods                                             |
| BS EN 1232      | Personal dosimetry pumps                                                                                                               | Test methods                                             |
| BS EN 12919     | Sampling pumps of flowrate over 5 l/min                                                                                                | Test methods                                             |
| BS EN 45544     | Electrical apparatus for the direct detection and measurement of toxic gases and vapours                                               |                                                          |
| BS ISO 15202    | Metals and metalloids                                                                                                                  | Inductively coupled plasma atomic emission spectrometry  |
| BS ISO 16200    | Volatile organic compounds                                                                                                             | Solvent desorption and gas chromatography                |

**Table 10.29 Compounds for which there are analytical methods recommended by NIOSH**

|                                                   |                                                                      |
|---------------------------------------------------|----------------------------------------------------------------------|
| Acenaphthene                                      | Benomyl                                                              |
| Acetaldehyde                                      | Benzaldehyde                                                         |
| Acetic acid                                       | Benz(c)acridine                                                      |
| Acetic anhydride                                  | 1,3-benzenediol                                                      |
| Acetone                                           | Benz(a)anthracene                                                    |
| Acetone cyanohydrin                               | Benz(a,h)anthracene                                                  |
| Acetonitrile (methyl cyanide)                     | Benz(a)anthrone                                                      |
| Acetylene dichloride (1,2-dichloroethylene)       | Benzene                                                              |
| Acetylene tetrabromide (tetrabromoethane)         | Benzene, chlorinated                                                 |
| Acetylene tetrachloride                           | Benzene-solubles                                                     |
| Acid mists                                        | Benzidine                                                            |
| Acrolein                                          | Benzidine-based dyes                                                 |
| Acrylonitrile                                     | Benzo Azurine G                                                      |
| Alachlor                                          | Benzo(a)fluoranthene                                                 |
| ALAD ( $\delta$ -aminolevulinic acid dehydratase) | Benzo(b)fluoranthene                                                 |
| Aldehydes (screening)                             | Benzo(j)fluoranthene                                                 |
| Aldecarb                                          | Benzo(k)fluoranthene                                                 |
| Aldrin                                            | Benzo(g,h,i)perylene                                                 |
| Alkaline dusts                                    | Benzopurpurine 4B                                                    |
| Allyl alcohol                                     | Benzo(a)pyrene                                                       |
| Allyl chloride                                    | Benzo(c)pyrene                                                       |
| Allyl glycidyl ether                              | Benzo(e)pyrene                                                       |
| Allyl trichloride                                 | Benzosulphonazole                                                    |
| Alumina                                           | Benzothiazole                                                        |
| Aluminium                                         | Benzoyl peroxide                                                     |
| Amines, aliphatic                                 | Benzyl chloride                                                      |
| Amines, aromatic                                  | Beryllium                                                            |
| Amino benzene                                     | Beryllium and compounds                                              |
| 4-Aminobiphenyl                                   | Bibenzyl                                                             |
| Aminoethanol compounds                            | Biphenyl (diphenyl)                                                  |
| bis (2-Aminoethyl) amine (diethylenetriamine)     | Biphenyl-phenyl ether mixture (phenyl ether-biphenyl vapour mixture) |
| <i>p</i> -Aminophenylarsonic acid                 | Bis(chloromethyl)ether                                               |
| 2-Aminopyridine                                   | 2,2-Bis[4-(2,3-epoxypropoxy)phenyl] propane                          |
| 2-Aminotoluene                                    | Bismuth                                                              |
| Ammonia                                           | Bisphenol A                                                          |
| Ammonium sulphamate                               | 2,2-Bis( <i>p</i> -chlorophenyl) 1,1,1-trichloroethane (DDT)         |
| Amorphous silica                                  | Boron carbide                                                        |
| <i>n</i> -Amyl acetate                            | Boron oxide                                                          |
| sec-Amyl acetate ( $\alpha$ -methylbutyl acetate) | Bioaerosol                                                           |
| Aniline                                           | Bitumen fume                                                         |
| Anisidine                                         | Bromotrifluoromethane                                                |
| Anthanthrene                                      | Bromoxynil                                                           |
| Anthracene                                        | Bromoxynil octanoate                                                 |
| Antimony                                          | Butadiene (1,3-butadiene)                                            |
| ANTU ( $\delta$ -naphthyl thiourea)               | 1-Butanethiol ( <i>n</i> -butyl mercaptan)                           |
| <i>p</i> -Arsanilic acid                          | 2-Butanone (methyl ethyl ketone or MEK)                              |
| Arsenic                                           | 2-Butoxy ethanol (butyl cellosolve)                                  |
| Arsenic trioxide                                  | sec-Butyl acetate                                                    |
| Arsine                                            | tert-Butyl acetate                                                   |
| Asbestos                                          | Butyl acetate ( <i>n</i> -Butyl acetate)                             |
| Aspartame                                         | sec-Butyl alcohol                                                    |
| Asphalt fume                                      | tert-Butyl alcohol                                                   |
| Atrazine                                          | Butyl alcohol ( <i>n</i> -butyl alcohol)                             |
| Azinphos methyl                                   | Butyl cellosolve (2-butoxy ethanol)                                  |
| Azelaic acid                                      | <i>n</i> -Butyl glycidyl ether                                       |
| Aziridine                                         | <i>n</i> -Butyl mercaptan                                            |
| Azo dyes                                          | <i>n</i> -Butylamine                                                 |
| Barium                                            | 1,3-Butylene glycol                                                  |

Table 10.29 Cont'd

|                                             |                                                              |
|---------------------------------------------|--------------------------------------------------------------|
| Butyraldehyde                               | Cobalt, metal, dust, and fume                                |
| <i>p</i> -tert-Butyltoluene                 | Congo red                                                    |
|                                             | Copper                                                       |
| Cadmium                                     | Copper dust and mists                                        |
| Cadmium and compounds                       | Copper fume                                                  |
| Calcium                                     | Crag herbicide I                                             |
| Calcium and compounds                       | Cresol, all isomers                                          |
| Calcium arsenate                            | Cristobalite                                                 |
| Calcium oxide                               | Crotonaldehyde                                               |
| Camphor                                     | Cryofluorane                                                 |
| Capsaicin                                   | Cumene                                                       |
| Captan                                      | Cyanide                                                      |
| Carbaryl® (Sevin)                           | Cyanuric acid                                                |
| Carbendazim                                 | Cyanazine                                                    |
| Carbitol                                    | Cyclohexane                                                  |
| Carbofuran                                  | Cyclohexanol                                                 |
| Carbon black                                | Cyclohexanone                                                |
| Carbon dioxide                              | Cyclohexene                                                  |
| Carbon disulphide                           | Cyclohexylamine                                              |
| Carbon, elemental                           | Cyclopentadiene                                              |
| Carbon monoxide                             |                                                              |
| Carbon tetrachloride                        | DBPC                                                         |
| Carbonyl chloride (phosgene)                | 2,4 D                                                        |
| 3-Carene                                    | 2,4-D acid                                                   |
| Chlordane                                   | 2,4-D 2-ethylhexyl ester                                     |
| Chloroacetic acid                           | 2,4-D 2-butoxyethyl ester                                    |
| Chloride                                    | DDT (2,2-Bis( <i>p</i> -chlorophenyl)-1,1,1-trichloroethane) |
| Chlorinated camphene (toxaphene)            | DDVP                                                         |
| Chlorinated diphenyl oxide                  | <i>n</i> -Decane                                             |
| Chlorine                                    | Demeton                                                      |
| 2-Chloro-1,3-butadiene (chloroprene)        | Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)           |
| Chlorodifluoroethane                        | 1,2-Diaminoethane (ethylene diamine)                         |
| 1-Chloro-2,3-epoxypropane (epichlorohydrin) | $\alpha$ -Dianisidine-based dyes                             |
| 4-Chloronitrobenzene                        | Diatomaceous earth                                           |
| 1-Chloro-1-nitropropane                     | Diazomethane                                                 |
| Chloroacetaldehyde                          | Diazonium salts                                              |
| $\alpha$ -Chloroacetophenone                | Dibenz(a,h)anthracene                                        |
| Chlorobenzene (monochlorobenzene)           | Diborane                                                     |
| $\alpha$ -Chlorobenzylidene malononitrile   | Dibromodifluoromethane                                       |
| Chlorobromomethane                          | 1,2-Dibromoethane (ethylene dibromide)                       |
| Chlorodiphenyl (42% chlorine)               | 2-Dibutylaminoethanol (aminoethanol compounds)               |
| Chlorodiphenyl (54% chlorine)               | Dibutyl phosphate                                            |
| 2-Chloroethanol (ethylene chlorohydrin)     | Dibutylphthalate                                             |
| Chloroform                                  | Dibutyl tin bis (isooctylmercaptoacetate)                    |
| Chloroform methyl ether                     | Dichloromethane                                              |
| <i>p</i> -Chlorophenol                      | 1,1-Dichloro-1-nitroethane                                   |
| Chloroprene                                 | $\alpha$ -Dichlorobenzene                                    |
| Chloroprotham                               | <i>p</i> -Dichlorobenzene                                    |
| Chloryrfos                                  | 3,3'-Dichlorobenzidine                                       |
| Chromic acid                                | Dichlorodifluoromethane (Refrigerant 12)                     |
| Chromium                                    | 1,1-Dichloroethane (ethylidene chloride)                     |
| Chromium fume                               | 1,2-Dichloroethane (ethylene dichloride)                     |
| Chromium, hexavalent                        | Dichloroethyl ether                                          |
| Chrysene                                    | 1,2-Dichloroethylene (acetylene dichloride)                  |
| Chrysotile                                  | Dichloromethane (methylene chloride)                         |
| Coal-tar naphtha (naphtha, coal tar)        | Dichloromonofluoromethane (Refrigerant 21)                   |
| Coal-tar pitch volatiles                    | 2,4-Dichlorophenoxyacetic acid and salts                     |
| Cobalt                                      | 1,2-Dichloropropane                                          |
| Cobalt and compounds                        | Dichlorotetrafluoroethane (Refrigerant 114)                  |

Table 10.29 Cont'd

|                                                                 |                                                                             |
|-----------------------------------------------------------------|-----------------------------------------------------------------------------|
| Dichloro-5-triazine-2,4,6-trione, sodium salt                   | 1,2-Epoxypropane (propylene oxide)                                          |
| Dichlorovos                                                     | 2,2-bis[4-(2,3-Epoxypropoxy) phenyl] propane                                |
| Dicrotophos                                                     | Ethanol (ethyl alcohol)                                                     |
| Dieldrin                                                        | Ethanolamine (aminoethanol compounds)                                       |
| Diesel exhaust                                                  | Ether                                                                       |
| Diethanolamine                                                  | Ethion                                                                      |
| 2-Diethylaminoethanol                                           | Ethoprop                                                                    |
| Diethylamine                                                    | 2-Ethoxyethanol                                                             |
| Diethylcarbamoyl chloride                                       | 2-Ethoxyethylacetate                                                        |
| Diethylene dioxide (dioxane)                                    | Ethyl acrylate                                                              |
| Diethylene glycol                                               | Ethyl alcohol (ethanol)                                                     |
| Diethylene glycol ether                                         | Ethyl benzene                                                               |
| Di-(2 ethyl hexyl) phthalate                                    | Ethyl bromide                                                               |
| Diethylenetriamine                                              | Ethyl butyl ketone (3-heptanone)                                            |
| Difluorodibromomethane                                          | Ethyl chloride                                                              |
| Difluorodichloromethane                                         | Ethyl ether                                                                 |
| Diglycidyl ether of Bisphenol A                                 | Ethyl formate                                                               |
| Dihydrocapsaicin                                                | Ethyl mercaptan                                                             |
| Diisobutyl ketone (2,6-dimethyl-4-heptanone)                    | Ethyl sec-amyl ketone (5-methyl-3-heptanone)                                |
| Diisopropylamine                                                | Ethyl silicate                                                              |
| Dimethoxymethane (methylal)                                     | O-Ethyl-O- <i>p</i> -nitrophenyl phenyl-phosphonothiolate phosphonate (EPN) |
| Dimethyl acetamide                                              | Ethylamine                                                                  |
| Dimethyl benzene (xylene)                                       | Ethylene chloride (ethylene dichloride)                                     |
| 1,3-Dimethyl butyl acetate (sec-hexyl acetate)                  | Ethylene chlorohydrin (2-chloroethanol)                                     |
| Dimethyl formamide                                              | Ethylenediamine                                                             |
| 2,6-Dimethyl-4-heptanone (diisobutyl ketone)                    | Ethylene dibromide (1,2-dibromoethane)                                      |
| Dimethyl sulphate                                               | Ethylene dichloride (1,2-dichloroethane)                                    |
| <i>N,N</i> -Dimethyl- <i>p</i> -toluidine                       | Ethylene glycol                                                             |
| Dimethylamine                                                   | Ethylene glycol dinitrate                                                   |
| 4-Dimethylaminoazobenzene                                       | Ethylene oxide                                                              |
| 2,4-Dimethylaminobenzene (xylidine)                             | Ethylene thiourea                                                           |
| <i>N,N</i> -dimethylaniline                                     | Ethylenimine                                                                |
| Dimethylarsenic acid                                            | di-2-Ethylhexylphthalate (di-sec-octyl phthalate)                           |
| 1,1-Dimethylhydrazine                                           | Ethylidene chloride (1,1-dichloroethane)                                    |
| Dimethylnitrosamine                                             | N-Ethylmorpholine                                                           |
| bis (Dimethylthiocarbamoyl) disulphide                          |                                                                             |
| Dinitrobenzene (all isomers)                                    | Fenamiphos                                                                  |
| Dinitro <i>o</i> -cresol                                        | Fibrous glass                                                               |
| Dinitrotoluene                                                  | Fluoranthene                                                                |
| Dioxane                                                         | Fluorene                                                                    |
| Diphenyl                                                        | Fluoride                                                                    |
| 4,4'-Methylenebisphenyl isocyanate (MDI)                        | Fluoroacetate, sodium                                                       |
| Dipropylene glycol methyl ether                                 | Fluorotrichloromethane (Refrigerant 11)                                     |
| Direct Black 38                                                 | Fonofos                                                                     |
| Direct Blue 6                                                   | Formaldehyde                                                                |
| Direct Blue 8                                                   | Formetanate.HCl                                                             |
| Direct Brown 95                                                 | Formic acid                                                                 |
| Direct Red 2                                                    | Furfural                                                                    |
| Direct Red 28                                                   | Furfuryl alcohol                                                            |
| Disulphotondiuron                                               |                                                                             |
| 2,6-Di- <i>tert</i> -butyl- <i>p</i> -cresol                    | Galena                                                                      |
| Dowtherm A (phenyl etherbiphenyl vapour mixture)                | Gallium                                                                     |
|                                                                 | Glutaraldehyde                                                              |
| Elemental carbon                                                | Glycerin mist                                                               |
| Elements                                                        | Glycidol (2,3-epoxy-1-propanol)                                             |
| Endrin                                                          | Glycols                                                                     |
| Epichlorohydrin (1-chloro-2,3-epoxypropane)                     |                                                                             |
| EPN (O-ethyl-O- <i>p</i> -nitrophenyl phenyl-phosphonothiolate) | Hafnium                                                                     |
| 2,3-Epoxy-1-propanol (glycidol)                                 | Heptachlor                                                                  |

Table 10.29 Cont'd

|                                                    |                                                   |
|----------------------------------------------------|---------------------------------------------------|
| Heptane                                            | Lithium hydroxide                                 |
| Heptanal                                           | LPG (liquefied petroleum gas)                     |
| 3-Heptanone (ethyl butyl ketone)                   |                                                   |
| 2-Heptanone (methyl ( <i>n</i> -amyl) ketone)      | MAPP (methyl acetylene/propadiene)                |
| Herbicides                                         | Magnesium                                         |
| Hexachlorobutadiene                                | Magnesium oxide fume                              |
| Hexachlorocyclopentadiene                          | Malathion                                         |
| Hexachloroethane                                   | Maleic anhydride                                  |
| Hexachloronaphthalene                              | Manganese                                         |
| Hexamethylene diisocyanate                         | Manganese fume                                    |
| Hexamethylenetetramine                             | MBK (2-hexanone)                                  |
| Hexanal                                            | MDI (4,4'-methylenebisphenyl isocyanate)          |
| Hexane                                             | MEK (2-butanone)                                  |
| 2-Hexanone                                         | Mercaptans                                        |
| Hexavalent chromium                                | Mercury                                           |
| 2-Hexanone (methyl butyl ketone or MBK)            | Mesityl oxide                                     |
| Hexone (methyl isobutyl ketone or MIBK)            | Metals in air                                     |
| sec-Hexyl acetate (1,3-dimethyl butyl acetate)     | Methamidophos                                     |
| Hippuric acid                                      | Methanol (methyl alcohol)                         |
| Hydrazine                                          | Methiocarb                                        |
| Hydrogen bromide                                   | Methomyl                                          |
| Hydrogen chloride                                  | 2-Methoxyethanol (methyl cellosolve)              |
| Hydrogen cyanide                                   | 2-Methoxyethyl acetate                            |
| Hydrogen fluoride                                  | Methozychlor                                      |
| Hydrogen sulphide                                  | Methyl( <i>n</i> -amyl)ketone (2-heptanone)       |
| Hydroquinone                                       | 5-Methyl-3-heptanone                              |
| 4-Hydroxy-4-methyl-2-pentanone (diacetone alcohol) | Methyl acetate                                    |
|                                                    | Methyl acetylene                                  |
| 2-Imidazolidinethione (ethylene thiourea)          | Methyl acetylene propadiene mixture               |
| Indeno[1,2,3- <i>cd</i> ]pyrene                    | Methyl acrylate                                   |
| Indium                                             | Methyl alcohol (methanol)                         |
| Iodine                                             | 4-Methylbenzenesulphonic acid                     |
| Iron                                               | Methylamyl ketone                                 |
| Iron oxide fume                                    | Methyl arsonic acid                               |
| Isoamyl acetate                                    | Methyl bromide                                    |
| Isoamyl alcohol                                    | $\alpha$ -Methyl butyl acetate (sec-amyl acetate) |
| Isobutyl acetate                                   | Methyl butyl ketone (2-hexanone)                  |
| Isobutyl alcohol                                   | Methyl cellosolve (2-methoxyethanol)              |
| Isobutyraldehyde                                   | Methyl cellosolve acetate                         |
| Isocyanates                                        | Methyl chloride                                   |
| Isophorone                                         | Methyl chloroform (1,1,1-trichloroethane)         |
| Isopropanol (isopropyl alcohol)                    | Methyl cyanide (acetonitrile)                     |
| Isopropyl acetate                                  | Methyl ethyl ketone (2-butanone)                  |
| Isopropyl alcohol (isopropanol)                    | Methyl ethyl ketone peroxide                      |
| Isopropyl benzene (cumene)                         | Methyl formate                                    |
| Isopropyl glycidyl ether                           | Methyl iodide                                     |
| Isopropylamine                                     | Methyl isoamyl acetate                            |
| 4,4'-Isopropylidenediphenol                        | Methyl isobutyl carbinol                          |
| Isovaleraldehyde                                   | Methyl isobutyl ketone (hexone)                   |
|                                                    | Methyl methacrylate                               |
| Kepone                                             | $\alpha$ -Methyl styrene                          |
| Kerosene                                           | Methylal (dimethoxymethane)                       |
| Ketene                                             | Methylamine                                       |
|                                                    | Methylcyclohexane                                 |
| Lead                                               | Methylcyclohexanol                                |
| Lead sulphide                                      | Methylcyclohexanone                               |
| Limonene                                           | 4,4'-Methylenebis (2-chloroaniline)               |
| Lindane                                            | 4,4'-Methylenebisphenyl isocyanate (MDI)          |
| Liquefied petroleum gas (LPG)                      | Methylene chloride (dichloromethane)              |
| Lithium                                            | 4',4'-Methylenedianiline                          |

Table 10.29 Cont'd

|                                                   |                                                  |
|---------------------------------------------------|--------------------------------------------------|
| 5-Methyl-3-heptanone                              | Organonitrogen pesticides                        |
| Methylhydrazine                                   | Organophosphorus pesticides                      |
| Metolachlor                                       | Oxamyl                                           |
| Methyl mercaptan                                  | Ozone                                            |
| Methyl parathion                                  | Oxygen                                           |
| Methyl phenol                                     |                                                  |
| N-Methyl-2-pyrrolidinone                          | Palladium                                        |
| Methyl tert-butyl ether                           | Paraquat                                         |
| Mevinphos®                                        | Parathion                                        |
| MLBK (hexone)                                     | Particulates                                     |
| Mineral spirits                                   | Pentamidine                                      |
| MOCA                                              | PCBs                                             |
| Molybdenum                                        | Pentachlorobenzene                               |
| Molybdenum insoluble compounds                    | Pentachloroethane                                |
| Molybdenum soluble compounds                      | Pentachloronaphthalene                           |
| Monochloroacetic acid                             | Pentachlorophenol                                |
| Monochlorobenzene (chlorobenzene)                 | Pentane                                          |
| Monocrotophos                                     | 2-Pentanone                                      |
| Monomethyl aniline                                | Perchloroethylene (tetrachloroethylene)          |
| Monomethyl hydrazine                              | Perylene                                         |
| Monomethylarsonic acid                            | Pesticides                                       |
| Morpholine                                        | Petroleum distillates (petroleum naphtha)        |
|                                                   | Petroleum naphtha (petroleum distillates)        |
| Naphtha, coal tar (coal-tar naphtha)              | Phenacylchloride                                 |
| Naphthalene                                       | Phenanthrene                                     |
| Naphthylamines                                    | Phenol                                           |
| α-Naphthyl thiourea                               | Phenyl ether                                     |
| Nickel                                            | Phenyl ether-biphenyl vapor mixture (Dowtherm A) |
| Nickel carbonyl                                   | Phenyl ethylene (styrene)                        |
| Nickel fume                                       | Phenyl glycidyl ether                            |
| Nicotine                                          | Phenylhydrazine                                  |
| Nitric acid                                       | Phenyloxirane                                    |
| Nitric oxide                                      | Phorate                                          |
| p-Nitroaniline                                    | Phosdrin                                         |
| Nitrobenzene                                      | Phosgene (carbonyl chloride)                     |
| Nitrobenzol                                       | Phosphate                                        |
| 4-Nitrobiphenyl                                   | Phosphine                                        |
| p-Nitrochlorobenzene                              | Phosphoric acid                                  |
| Nitroethane                                       | Phosphorus (white, yellow)                       |
| Nitrogen peroxide                                 | Phosphorus pentachloride                         |
| 2-Nitropropane                                    | Phosphorus trichloride                           |
| Nitrogen dioxide                                  | Phthalic anhydride                               |
| Nitroglycerin                                     | Picric acid                                      |
| Nitroglycol                                       | Pinene                                           |
| Nitromethane                                      | Platinum, soluble salts                          |
| Nitrosamines                                      | PNA's                                            |
| N-Nitrosodimethylamine                            | Polyacrylate                                     |
| Nitrous oxide                                     | Polychlorinated biphenyls (PCBs)                 |
| Nitrotoluene                                      | Polymethylsiloxane                               |
| Nuisance dusts                                    | Polynuclear aromatic hydrocarbons (PNA's)        |
|                                                   | Potassium                                        |
| Octachloronaphthalene                             | Potassium hydroxide                              |
| Octamethylcyclotetrasiloxane                      | Propane                                          |
| Octane                                            | Propanol (Propyl alcohol)                        |
| 1-Octanethiol                                     | Propham                                          |
| di-sec-Octyl phthalate (di-2-ethylhexylphthalate) | Propionaldehyde                                  |
| Oil mist                                          | Propxur                                          |
| Organic solvents                                  | n-Propyl acetate                                 |
| Organo(alkyl)mercury                              | Propyl alcohol (propanol)                        |
| Organoarsenicals                                  | n-Propyl nitrate                                 |



Table 10.29 Cont'd

|                                                      |                                                             |
|------------------------------------------------------|-------------------------------------------------------------|
| Propylene dichloride                                 | Tellurium                                                   |
| Propylene glycol                                     | Tellurium hexafluoride                                      |
| Propylene oxide (1,2-epoxypropane)                   | TEPP                                                        |
| Propyne                                              | Terbufos                                                    |
| Pyrene                                               | Terpenes                                                    |
| Pyrethrum                                            | Terphenyl                                                   |
| Pyridine                                             | Tetrabromoethane (acetylene tetrabromide)                   |
|                                                      | Tetrabutyltin                                               |
| Quartz (silica, crystalline)                         | 1,1,1,2-Tetrachloro-2,2-difluoroethane                      |
| Quinone                                              | 1,1,2,2-Tetrachloro-1,2-difluoroethane<br>(Refrigerant 112) |
| Refrigerant 11 (fluorotrichloromethane)              | 1,2,4,5-Tetrachlorobenzene                                  |
| Refrigerant 113 (1,1,2-trichloro-1,2,2-fluoroethane) | 1,1,2,2-Tetrachloroethane                                   |
| Refrigerant 114 (dichlorotetrafluoroethane)          | Tetrachloroethylene (perchloroethylene)                     |
| Refrigerant 12 (dichlorodifluoromethane)             | Tetrachloromethane (carbon tetrachloride)                   |
| Refrigerant 21 (dichloromonofluoromethane)           | Tetrachloronaphthalene                                      |
| Resorcinol                                           | Tetraethyl lead                                             |
| Rhodium                                              | Tetraethylene glycol                                        |
| Rhodium, metal fume and dust                         | Tetraethyl pyrophosphate                                    |
| Rhodium, soluble salts                               | Tetrahydrofuran                                             |
| Ribavirin                                            | Tetramethyl lead (as Pb)                                    |
| Ronnel                                               | Tetramethyl succinonitrile                                  |
| Rotenone                                             | Tetramethyl thiourea                                        |
| Rubber solvent                                       | Tetramethyl thiuram disulphide (thiram)                     |
| Rubidium                                             | Tetranitromethane                                           |
|                                                      | Tetryl (2,4,6-Trinitrophenylmethyl-nitramine)               |
| Selenium                                             | Thallium                                                    |
| Sevin (carbaryl)                                     | Thiobencarb                                                 |
| Silica, amorphous                                    | Thiopene                                                    |
| Silica, crystalline                                  | Thiram (tetramethyl thiuram disulphide)                     |
| Silica in coal mine dust                             | Tin                                                         |
| Silicon                                              | Tin, organic compounds                                      |
| Silicon dioxide                                      | Tissue preparation                                          |
| Silver                                               | Titanium                                                    |
| Silver, metal and soluble compounds                  | Titanium diboride                                           |
| Simazine                                             | Titanium dioxide                                            |
| Sodium                                               | <i>o</i> -Tolidine based dyes                               |
| Sodium dichloroisocyanate dihydrate                  | Toluene                                                     |
| Sodium fluoroacetate                                 | 2,4 and 2,6-Toluenediamine                                  |
| Sodium-2,4-dichlorophenoxyethyl sulphate             | Toluene-2,4-diisocyanate (TDI)                              |
| Sodium hexafluoroaluminate                           | Toluene-2,6-diisocyanate                                    |
| Sodium hydroxide                                     | <i>p</i> -Toluene sulphonic acid                            |
| Stibine                                              | <i>o</i> -Toluidine                                         |
| Stoddard solvent                                     | Toxaphene (chlorinated camphene)                            |
| Strontium                                            | Tribromomethane                                             |
| Strychnine                                           | Tributyltin chloride                                        |
| Styrene (vinyl benzene)                              | Tributyl phosphate                                          |
| Styrene oxide                                        | 1,1,2-Trichloro-1,2,2-trifluoroethane (Refrigerant 113)     |
| Sulphate                                             | 1,2,4-Trichlorobenzene                                      |
| Sulphite                                             | 1,1,1-Trichloroethane (Methyl chloroform)                   |
| Sulprofos                                            | 1,1,2-Trichloroethane                                       |
| Sulphur dioxide                                      | Trichloroethylene                                           |
| Sulphur hexafluoride                                 | Trichloroisocyanuric acid                                   |
| Sulphuric acid                                       | Trichloromethane                                            |
| Sulphuryl fluoride                                   | Trichloromonofluoromethane (Fluorotrichloromethane)         |
| Systox                                               | Trichloronaphthalene                                        |
|                                                      | 2,4,5-Trichlorophenoxyacetic acid and salts                 |
| 2,4,5-T                                              | 1,2,3-Trichloropropane                                      |
| TDI (Toluene 2,4-diisocyanate)                       | 1,3,5-Trichloro-s-triazine-2,4,6-trione                     |
| Tantalum                                             | Tricyclohexyltin hydroxide                                  |

Table 10.29 Cont'd

|                                              |                                      |
|----------------------------------------------|--------------------------------------|
| 1,1,2-Trichloro-1,2,2-trifluoroethane        | Vinyl chloride                       |
| Tridymite                                    | Vinyl toluene                        |
| Triethanolamine                              | Vinylidene chloride                  |
| Triethylamine                                | Volatile organic compounds           |
| Triethylene glycol                           |                                      |
| Triethylenetetramine                         | Warfarin                             |
| Trifluoromonobromomethane                    | Wood alcohol                         |
| Trimellitic anhydride                        |                                      |
| 2,4,7-Trinitro-9-fluorenone                  | Xylene (xylol or dimethyl benzene)   |
| 2,4,6-Trinitrophenylmethylnitramine (Tetryl) | Xylidene (2,4-dimethylamino-benzene) |
| Triorthocresyl phosphate                     | Xylol (xylene)                       |
| Triphenyl phosphate                          |                                      |
| Tungsten                                     | Yttrium                              |
| Turpentine                                   |                                      |
|                                              | Zinc                                 |
| Vanadium                                     | Zinc and compounds                   |
| Vanadium, V <sub>2</sub> O <sub>5</sub> fume | Zinc fume                            |
| Valeraldehyde                                | Zinc oxide                           |
| Vinyl acetate                                | Zirconium compounds                  |
| Vinyl benzene (styrene)                      | Zirconium oxide                      |
| Vinyl bromide                                |                                      |

When compliance with hygiene standards is assessed using short-term sampling (e.g. 15 min), the number of samples obtainable within an 8 hr shift is 32. The average of these will indicate whether or not exposures have exceeded the TWA hygiene standard. When fewer than 32 results are available it is necessary to lower the acceptable upper limit for the average below the hygiene standard to compensate for the lack of data. The following defines the upper acceptable limit to the average,  $\bar{x}_{\max}$ , thus:

$$\bar{x}_{\max} = (\text{TWA hygiene standard}) - 1.6 \left( \frac{1}{\sqrt{n}} - \frac{1}{32} \right) \sigma$$

where  $n$  = number of results,  $\sigma$  = standard deviation. If  $\sigma$  is unknown from previous results, an estimate can be made from a few samples and the maximum acceptance limit is hygiene standard ( $k \times \text{range}$ ), where  $k$  is obtained from Table 10.31. If the calculated limit is below the observed range, compliance can be assumed for that day, although the statistical significance over longer periods needs consideration.

For routine monitoring, frequency will be influenced by the level of exposure. The further the levels depart from the standard, the less the need for routine monitoring. A suggested guide is: personal monitoring once per month if the TWA exposures are  $1-2 \times$  hygiene standard

once per quarter if  $0.5-1$  or  $2-4 \times$  hygiene standard

once per year if  $0.1-0.5$  or  $4-10 \times$  hygiene standard.

Routine monitoring becomes superfluous if exposures are very low (i.e. below  $0.1 \times$  hygiene standard) or very high (e.g.  $10 \times$  hygiene standard), although where standards are Control Limits routine sampling should be considered when exposures exceed  $0.1$  CL. (The frequencies refer to monitoring the entire shift period for every 10 employees.) Table 10.32 offers guidance for monitoring strategies for compounds assigned OELs (Chapter 5) through legislative requirements.

**Table 10.30 Methods for sampling and analysis of a range of air pollutants**

| <i>Substance</i>                               | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Abate                                          | F (5 m PVC)                           | 250                                           | 2000                                                      | G                                          |
| Acetaldehyde                                   | I                                     | 10                                            | 2000                                                      | C                                          |
| Acetic acid                                    | I                                     | 100                                           | 2500                                                      | Titration                                  |
| Acetic anhydride                               | I                                     | 100                                           | 1000                                                      | C                                          |
| Acetone                                        | CT                                    | 2                                             | 200                                                       | GLC                                        |
| Acetonitrile                                   | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Acetylene dichloride, see 1,2-Dichloroethylene |                                       |                                               |                                                           |                                            |
| Acetylene tetrabromide                         | ST                                    | 100                                           | 1000                                                      | GLC                                        |
| Acrolein                                       | I                                     | 10                                            | 1500                                                      | C                                          |
|                                                | AT                                    | 6                                             | 200                                                       | GLC                                        |
| Acrylamide                                     | I                                     |                                               | 1000                                                      |                                            |
|                                                | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Acrylonitrile                                  | CT                                    | 20                                            | 200                                                       | GLC                                        |
| Aldrin                                         | F + I (GF)                            | 180                                           | 1000                                                      | GLC                                        |
| Allyl alcohol                                  | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Allyl chloride                                 | CT                                    | 100                                           | 1000                                                      | GLC                                        |
| Allyl glycidyl ether (AGE)                     | CT                                    | 10                                            | 50                                                        | GLC                                        |
| Allyl propyl disulphide                        | CT                                    | 10                                            | 1000                                                      | GLC                                        |
| Alundum® (Al <sub>2</sub> O <sub>3</sub> )     | F (5 m PVC)                           | 250                                           | 2000                                                      | G                                          |
| 4-Aminodiphenyl                                | F (0.8 m MCEF)                        | 540                                           | 4000                                                      | C                                          |
| 2-Aminoethanol, see Ethanolamine               |                                       |                                               |                                                           |                                            |
| 2-Aminopyridine                                |                                       |                                               |                                                           |                                            |
| Ammonia                                        | I                                     | 5                                             | 1000                                                      | C                                          |
|                                                | OT                                    | I                                             | 100                                                       | LDDT                                       |
|                                                | P                                     |                                               |                                                           | PC                                         |
| Ammonium chloride – fume                       | F (0.8 m MCEF)                        | 100                                           | 2000                                                      | C                                          |
| Ammonium sulphamate (ammate)                   | F (5 m PVC)                           | 250                                           | 2000                                                      | G                                          |
| <i>n</i> -Amyl acetate                         | CT                                    | 10                                            | 200                                                       | GLC                                        |
| sec-Amyl acetate                               | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Aniline                                        | ST                                    | 20                                            | 200                                                       | GLC                                        |
| Anisidine ( <i>o</i> -, <i>p</i> -isomers)     | ST                                    | 15                                            | 200                                                       | GLC                                        |
| Antimony and compounds (as Sb)                 | F (0.8 m MCEF)                        | 360                                           | 1500                                                      | AAS                                        |
| ANTU ( $\alpha$ -naphthylthiourea)             | F (0.8 m MCEF)                        | 300                                           | 1500                                                      | GLC                                        |
| Arsenic and compounds (as As)                  | F (0.8 m MCEF)                        | 90                                            | 2000                                                      | AAS                                        |
| Arsenic trioxide production (as As)            |                                       | 30                                            | 1700                                                      | C                                          |
| Arsine                                         | CT                                    | 10                                            | 200                                                       | AAS                                        |
| Asbestos                                       | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | (microscopic fibre count)                  |
| Asphalt (petroleum) fumes                      | F (2 m PVC)                           | 250                                           | 2000                                                      | G                                          |
| Azinophos methyl                               | I                                     | 100                                           | 1000                                                      | GLC                                        |

|                                              |                |     |      |                                                     |
|----------------------------------------------|----------------|-----|------|-----------------------------------------------------|
| Barium (soluble compounds)                   | F (0.8 m MCEF) | 180 | 1500 | AAS                                                 |
| Benzene                                      | CT             | 12  | 200  | GLC                                                 |
|                                              | OT             | 2   |      | LDDT                                                |
| Benzidine production                         | F (0.8 m MCEF) | 480 | 4000 | C                                                   |
| <i>p</i> -Benzoquinone, <i>see</i> Quinone   |                |     |      |                                                     |
| Benzo(1)pyrene                               | I              | 30  | 1000 | C                                                   |
| Benzo(a)pyrene                               |                |     |      |                                                     |
| Benzyl chloride                              | CT             | 10  | 200  | GLC                                                 |
| Beryllium                                    | F (0.8 m MCEF) | 270 | 1500 | AAS (30 min allowed at<br>0.025 mg/m <sup>3</sup> ) |
| Biphenyl                                     | CT             | 30  | 200  | GLC                                                 |
| Bismuth telluride                            | F (0.8 m MCEF) | 100 | 1500 | AAS                                                 |
| Boron oxide                                  | F (2 m PVC)    | 60  | 1000 | G                                                   |
| Boron trifluoride                            | F + I          | 30  | 2500 | C                                                   |
| Bromine                                      | I              | 45  | 1000 | C                                                   |
| Bromine pentafluoride                        | I              | 15  | 2500 | ISE                                                 |
| Bromoform                                    | CT             | 10  | 200  | GLC                                                 |
| Butadiene (1,3-butadiene)                    | CT             | 1   | 50   | GLC                                                 |
| Butanethiol, <i>see</i> Butyl mercaptan      |                |     |      |                                                     |
| 2-Butanone                                   | CT             | 10  | 200  | GLC                                                 |
| 2-Butoxyethanol (butyl cellosolve)           | CT             | 10  | 200  | GLC                                                 |
| <i>n</i> -Butyl acetate                      | CT             | 10  | 200  | GLC                                                 |
| sec-Butyl acetate                            | CT             | 10  | 200  | GLC                                                 |
| tert-Butyl acetate                           | CT             | 10  | 200  | GLC                                                 |
| <i>n</i> -Butyl alcohol                      | CT             | 10  | 200  | GLC                                                 |
| sec-Butyl alcohol                            | CT             | 10  | 200  | GLC                                                 |
| tert-Butyl alcohol                           | CT             | 10  | 200  | GLC                                                 |
| Butylamine                                   | I              | 15  | 1000 | C                                                   |
| Butyl cellosolve, <i>see</i> 2-Butoxyethanol |                |     |      |                                                     |
| tert-Butyl chromate (as CrO <sub>3</sub> )   | F (0.8 m MCEF) | 23  | 1500 | C                                                   |
| <i>n</i> -Butyl glycidyl ether               | CT             | 10  | 200  | GLC                                                 |
| <i>n</i> -Butyl lactate                      | F (0.8 m MCEF) | 30  | 1000 | GLC                                                 |
| Butyl mercaptan                              | CT             | 10  | 1000 | GLC                                                 |
| <i>p</i> -tert-Butyltoluene                  | CT             | 10  | 200  | GLC                                                 |
| Cadmium, dust and salts (as Cd)              | F (0.8 m MCEF) | 15  | 1000 | AAS                                                 |
| Cadmium, fume (as Cd)                        |                |     |      |                                                     |
| Cadmium oxide fume (as Cd)                   | F (0.8 m MCEF) | 25  | 1500 | AAS                                                 |
| Calcium arsenate (as As)                     | F (0.8 m MCEF) | 500 | 1500 | AAS                                                 |
|                                              |                |     |      | C                                                   |
| Calcium carbonate/marble                     | F              |     |      | G (nuisance dust)                                   |
| Calcium oxide                                | F (0.8 m MCEF) | 85  | 1500 | AAS                                                 |
| Camphor, synthetic                           | CT             | 10  | 200  | GLC                                                 |
| Caprolactam                                  |                |     |      |                                                     |
| dust                                         | F (0.8 m MCEF) |     |      | GLC                                                 |
| vapour                                       | I              |     |      | GLC                                                 |

Table 10.30 Cont'd

| <i>Substance</i>                                      | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|-------------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Carbaryl (Sevin®)                                     | F (GF)                                | 90                                            | 1500                                                      | C (do not use Tenite holder)               |
| Carbon black                                          | F (2 m PVC)                           | 200                                           | 1700                                                      | G (stainless steel support screen)         |
| Carbon dioxide                                        | (air bag)                             | 4                                             | 50                                                        | GLC                                        |
| Carbon disulphide                                     | CT                                    | 6                                             | 200                                                       | GLC (used with drying tube)                |
| Carbon monoxide                                       | M                                     |                                               | 100                                                       | (dosimeter)                                |
|                                                       | OT                                    | 1                                             | 20                                                        | LDDT                                       |
| Carbon tetrachloride                                  | CT                                    | 5                                             | 1000                                                      | GLC (10 min allowed at 200 ppm)            |
| Cellulose (paper fibre)                               | F                                     |                                               |                                                           | G (nuisance duet)                          |
| Chlordane                                             | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Chlorinated camphene                                  | F (0.8 m MCEF)                        | 15                                            | 1000                                                      | GLC                                        |
| Chlorinated diphenyl oxide                            | F (0.8 m MCEF)                        | 90                                            | 1000                                                      | GLC                                        |
| Chlorine                                              | I                                     | 30                                            | 2000                                                      | C                                          |
| Chlorine dioxide                                      | I                                     | 40                                            | 1000                                                      | C                                          |
| Chlorine trifluoride                                  | I                                     | 15                                            | 1000                                                      | ISE                                        |
| Chloroacetaldehyde                                    | CT                                    | 10                                            | 1000                                                      | GLC                                        |
| Chloroacetophenone (phenacyl chloride)                | CT                                    | 100                                           | 1000                                                      | GLC                                        |
| Chlorobenzene (monochlorobenzene)                     | CT                                    | 10                                            | 200                                                       | GLC                                        |
| α-Chlorobenzylidene malononitrile (OCBM)              | CT                                    | 10                                            | 1000                                                      | GLC                                        |
| Chlorobromomethane/bromochloromethane                 | CT                                    | 5                                             | 200                                                       | GLC                                        |
| 2-Chloro-1,3-butadiene, <i>see</i> β-Chloroprene      |                                       |                                               |                                                           |                                            |
| Chlorodiphenyl (42% chlorine)                         | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
|                                                       | OT                                    | 50                                            | 200                                                       | GLC                                        |
| Chlorodiphenyl (54% chlorine)                         | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
|                                                       | OT                                    | 50                                            | 200                                                       | GLC                                        |
| 1-Chloro,2,3-epoxy-propane, <i>see</i> Epichlorhydrin |                                       |                                               |                                                           |                                            |
| 2-Chloroethanol, <i>see</i> Ethylene chlorhydrin      |                                       |                                               |                                                           |                                            |
| Chloroethylene, <i>see</i> Vinyl chloride             |                                       |                                               |                                                           |                                            |
| Chloroform (trichloromethane)                         | CT                                    | 15                                            | 1000                                                      | GLC                                        |
| bis-Chloromethyl ether                                | CT                                    | 30                                            | 200                                                       | GLC                                        |
| 1-Chloro-1-nitropropane                               | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Chloropicrin                                          | I                                     | 100                                           | 1000                                                      | C                                          |
| β-Chloroprene                                         | CT                                    | 3                                             | 50                                                        | GLC                                        |
| 2-Chloro 6-trichloromethyl pyridine (N-Serve®)        | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Chromates, certain insoluble forms                    | F (0.8 m MCEF)                        | 90                                            | 1500                                                      | AAS                                        |
| Chromic acid and chromates (as Cr)                    | F (5 m PVC)                           | 22.5                                          | 1000                                                      | C                                          |

|                                                                                                        |                    |     |      |                               |
|--------------------------------------------------------------------------------------------------------|--------------------|-----|------|-------------------------------|
| Chromium, soluble chromic and chromous salts (as Cr)                                                   | F (0.8 m MCEF)     | 90  | 1500 | AAS                           |
| Coal tar pitch volatiles, see Particulate polycyclic aromatic hydrocarbons (PPAH), as benzene solubles |                    |     |      |                               |
| Cobalt metal, dust and fume (as Co)                                                                    | F (0.8 m MCEF)     | 720 | 1500 | AAS                           |
| Copper                                                                                                 |                    |     |      |                               |
| fume                                                                                                   | F (0.8 m MCEF)     | 720 | 1500 | AAS                           |
| dusts and mists (as Cu)                                                                                | F (0.8 m MCEF)     | 90  | 1500 | AAS                           |
| Corundum (Al <sub>2</sub> O <sub>3</sub> )                                                             | F                  |     |      | G (nuisance dust)             |
| Cotton dust (raw)                                                                                      | F (5 m PVC)        | 540 | 1500 | G                             |
| Crag® herbicide                                                                                        | F                  | 100 | 2000 | G                             |
| Cresol, all isomers                                                                                    | ST                 | 20  | 200  | GLC                           |
| Crotonaldehyde                                                                                         | CT                 | 20  | 200  | GLC                           |
|                                                                                                        | I                  | 100 | 2000 | C                             |
| Cumene                                                                                                 | CT                 | 10  | 200  | GLC                           |
| Cyanides (as CN)                                                                                       | F + 1 (0.8 m MCEF) | 90  | 1500 | ISE                           |
|                                                                                                        |                    | 1   | 20   | LDDT                          |
| Cyanogen                                                                                               | I                  | 15  | 500  | C                             |
| Cyclohexane                                                                                            | CT                 | 2.5 | 200  | GLC                           |
| Cyclohexanol                                                                                           | CT                 | 10  | 200  | GLC                           |
| Cyclohexanone                                                                                          | CT                 | 40  | 1000 | GLC                           |
| Cyclohexene                                                                                            | CT                 | 5   | 200  | GLC                           |
| Cyclohexylamine                                                                                        | I                  | 10  | 2000 | C                             |
| Cyclopentadiene                                                                                        | CT                 | 10  | 200  | GLC                           |
| 2,4-D (2,4-Diphenoxy-acetic acid)                                                                      | I                  | 100 | 1000 | GLC                           |
| DDT (Dichlorodiphenyltrichloroethane)                                                                  | F(GF)              | 90  | 1500 | GLC                           |
| DDVP, see Dichlorvos                                                                                   |                    |     |      |                               |
| Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)                                                     | CT                 | 10  | 200  | GLC                           |
| 1,2-Diaminoethane, see Ethylenediamine                                                                 |                    |     |      |                               |
| Diazomethane                                                                                           | OT                 | 10  | 200  | GLC (XAD-2 resin tube)        |
| Dibrom®                                                                                                | I                  | 100 | 1000 | GLC                           |
| 1,2-Dibromoethane                                                                                      | CT                 | 1   | 200  | GLC (5 min allowed at 50 ppm) |
| 2- <i>n</i> -Dibutylaminoethanol                                                                       |                    |     |      |                               |
| Dibutyl phosphate                                                                                      |                    |     |      |                               |
| Dibutyl phthalate                                                                                      | F (0.8 m MCEF)     | 30  | 1000 | GLC                           |
| Dichloracetylene                                                                                       |                    |     |      |                               |
| o-Dichlorobenzene                                                                                      | CT                 | 10  | 200  | GLC                           |
| p-Dichlorobenzene                                                                                      | CT                 | 3   | 50   | GLC                           |
| Dichlorobenzidine                                                                                      |                    |     |      |                               |
| Dichlorodifluoromethane                                                                                | CT                 | 3   | 50   | GLC                           |
| 1,3-Dichloro-5,5-dimethyl hydantoin                                                                    | I                  | 100 | 1000 | C                             |

Table 10.30 Cont'd

| <i>Substance</i>                                                        | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup>    |
|-------------------------------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|-----------------------------------------------|
| 1,1-Dichloroethane                                                      | CT                                    | 10                                            | 200                                                       | GLC                                           |
| 1,2-Dichloroethane                                                      | CT                                    | 3                                             | 200                                                       | GLC (12 min allowed at 200 ppm)               |
| 1,2-Dichloroethylene                                                    | CT                                    | 3                                             | 200                                                       | GLC                                           |
| Dichloroethyl ether                                                     | CT                                    | 15                                            | 1000                                                      | GLC                                           |
| Dichloromethane, see Methylene chloride                                 |                                       |                                               |                                                           |                                               |
| Dichloromonofluoromethane                                               | CT                                    | 3                                             | 50                                                        | GLC (use 2 large charcoal tubes back-to-back) |
| 1,1-Dichloro-1-nitroethane                                              | CT                                    | 15                                            | 1000                                                      | GLC (15 min sample)                           |
| 1,2-Dichloropropane, see Propylene dichloride                           |                                       |                                               |                                                           |                                               |
| Dichlorotetrafluoroethane                                               | CT                                    | 3                                             | 50                                                        | GLC                                           |
| Dichlorvos (DDVP)                                                       | I                                     | 100                                           | 1000                                                      | GLC                                           |
| Dieldrin                                                                | F (GF)                                | 180                                           | 1500                                                      | GLC                                           |
| Diethylamine                                                            | ST                                    | 50                                            | 1000                                                      | GLC                                           |
| Diethylaminoethanol                                                     | I                                     | 30                                            | 1000                                                      | C                                             |
| Diethylene triamine                                                     | I                                     | 100                                           | 1500                                                      | C                                             |
| Diethyl ether, see Ethyl ether                                          |                                       |                                               |                                                           |                                               |
| Diethyl phthalate                                                       | F (0.8 m MCEF)                        | 30                                            | 1000                                                      | GLC                                           |
| Difluorodibromomethane                                                  | CT                                    | 10                                            | 200                                                       | GLC                                           |
| Diglycidyl ether                                                        | CT                                    | 15                                            | 1000                                                      | GLC                                           |
| Dimethoxyethane, see Methylal                                           |                                       |                                               |                                                           |                                               |
| Diisobutyl ketone                                                       | CT                                    | 12                                            | 200                                                       | GLC                                           |
| Diisopropylamine                                                        | I                                     | 15                                            | 200                                                       | C                                             |
| Dimethyl acetamide                                                      | ST                                    | 50                                            | 1000                                                      | GLC                                           |
| Dimethylamine                                                           | ST                                    | 50                                            | 200                                                       | GLC                                           |
| Dimethylaminobenzene, see Xylidene                                      |                                       |                                               |                                                           |                                               |
| Dimethylaniline (N,N-dimethylaniline)                                   | CT                                    | 20                                            | 200                                                       | GLC                                           |
|                                                                         | ST                                    | 5                                             | 200                                                       |                                               |
| Dimethylbenzene, see Xylene                                             |                                       |                                               |                                                           |                                               |
| Dimethyl-1,2-dibromo-2-dichloroethyl phosphate, see Dibrom <sup>®</sup> |                                       |                                               |                                                           |                                               |
| Dimethylformamide                                                       | ST                                    | 50                                            | 1000                                                      | GLC                                           |
| 2,6-Dimethyl-4-heptanone, see Diisobutyl ketone                         |                                       |                                               |                                                           |                                               |
| 1,1-Dimethylhydrazine                                                   | I                                     | 100                                           | 1000                                                      | C                                             |
| Dimethylphthalate                                                       | CT                                    | 20                                            | 200                                                       | GLC                                           |
| Dimethyl sulphate                                                       |                                       |                                               |                                                           |                                               |
| Dinitrobenzene (all isomers)                                            | I                                     | 100                                           | 1000                                                      | C                                             |
| Dinitro- <i>o</i> -cresol                                               | CT                                    | 60                                            | 200                                                       | GLC                                           |

|                                                                               |             |     |      |                                       |
|-------------------------------------------------------------------------------|-------------|-----|------|---------------------------------------|
| Dinitrotoluene                                                                | I           | 100 | 1000 | C                                     |
| Dioxane (tech. grade)                                                         | CT          | 10  | 200  | GLC                                   |
| Diphenyl, <i>see</i> biphenyl                                                 |             |     |      |                                       |
| Diphenylmethane diisocyanate, <i>see</i> Methylene bisphenyl isocyanate (MDI) |             |     |      |                                       |
| Dipropylene glycol methyl ether                                               | CT          | 10  | 200  | GLC                                   |
| Di-sec, Octyl phthalate (di-2-ethylhexylphthalate)                            | CT          | 30  | 200  | GLC                                   |
| Dust, inert or nuisance respirable total                                      | F (5 m PVC) | 102 | 1700 | G (use cyclone but no Tenite holders) |
| Emery                                                                         | F           |     |      | G (nuisance dust)                     |
| Endrin                                                                        | I           | 100 | 1000 | GLC                                   |
| Epichlorhydrin                                                                | CT          | 20  | 200  | GLC                                   |
| EPN                                                                           | F (GF)      | 120 | 1500 | GLC                                   |
| 1,2-Epoxypropane, <i>see</i> Propylene oxide                                  |             |     |      |                                       |
| 2,3-Epoxy-1-Propanol, <i>see</i> Glycidol                                     |             |     |      |                                       |
| Ethanethiol, <i>see</i> Ethyl mercaptan                                       |             |     |      |                                       |
| Ethanolamine                                                                  | CT          | 20  | 200  | GLC                                   |
| 2-Ethoxyethanol                                                               | CT          | 10  | 200  | GLC                                   |
| 2-Ethoxyethyl acetate (cellosolve acetate)                                    | CT          | 10  | 200  | GLC                                   |
| Ethyl acetate                                                                 | CT          | 6   | 200  | GLC                                   |
| Ethyl acrylate                                                                | CT          | 10  | 200  | GLC                                   |
| Ethyl alcohol (ethanol)                                                       | CT          | 1   | 50   | GLC                                   |
| Ethylamine                                                                    | ST          | 30  | 200  | GLC                                   |
| Ethyl sec-amyl ketone (5-methyl-3-heptanone)                                  | CT          | 10  | 200  | GLC                                   |
| Ethyl benzene                                                                 | CT          | 10  | 200  | GLC                                   |
| Ethyl bromide                                                                 | CT          | 4   | 200  | GLC                                   |
| Ethylbutyl ketone (3-heptanone)                                               | CT          | 10  | 200  | GLC                                   |
| Ethyl chloride                                                                |             |     |      |                                       |
| Ethyl ether                                                                   | CT          | 3   | 200  | GLC                                   |
| Ethyl formate                                                                 | CT          | 10  | 200  | GLC                                   |
| Ethyl silicate                                                                | OT          | 9   | 50   | GLC                                   |
| Ethylene chlorohydrin                                                         | CT          | 20  | 200  | GLC                                   |
| Ethylenediamine                                                               | I           | 30  | 1000 | C                                     |
| Ethylene dibromide, <i>see</i> 1,2-Dibromoethane                              |             |     |      |                                       |
| Ethylene dichloride, <i>see</i> 1,2-Dichloroethane                            |             |     |      |                                       |
| Ethylene glycol dinitrate and/or nitroglycerine                               | OT          | 15  | 1000 | GLC (Tenax tube, 5 min sample)        |
| Ethylene glycol monomethyl ether acetate (methyl cellosolve acetate)          | CT          | 20  | 200  | GLC                                   |
| Ethylene oxide                                                                | CT          | 5   | 50   | GLC (use 2 back-to-back large tubes)  |
| Ethylidene chloride, <i>see</i> 1,1-Dichloroethane                            |             |     |      |                                       |
| N-Ethylmorpholine                                                             | CT          | 10  | 200  | GLC                                   |



Table 10.30 Cont'd

| <i>Substance</i>                            | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|---------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Ferbam                                      | F (0.8 m MCEF)                        | 150                                           | 1500                                                      | C                                          |
| Ferrovandium dust                           | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | AAS                                        |
| Fluoride (as F)                             | I                                     | 10                                            | 2500                                                      | ISE                                        |
|                                             | F                                     |                                               |                                                           |                                            |
| Fluorotrichloromethane                      | CT                                    | 4                                             | 50                                                        | GLC                                        |
| Formaldehyde                                | I                                     | 25                                            | 1000                                                      | C (10 min allowed at 10 ppm)               |
|                                             | AT                                    | 6                                             | 200                                                       | GLC                                        |
| Formic acid                                 | I                                     | 100                                           | 1000                                                      | GLC                                        |
|                                             |                                       |                                               |                                                           | C                                          |
| Furfural                                    | CT                                    | 20                                            | 200                                                       | GLC                                        |
|                                             | AT                                    | 6                                             | 200                                                       | GLC                                        |
| Furfuryl alcohol                            | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Glass, fibrous or dust                      | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Glycerin mist                               | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Glycidol (2,3-epoxy-1-propanol)             | CT                                    | 50                                            | 1000                                                      | GLC                                        |
| Glycol monoethyl ether, see 2-Ethoxyethanol |                                       |                                               |                                                           |                                            |
| Graphite (synthetic)                        | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Guthion®, see Azinphos-methyl               |                                       |                                               |                                                           |                                            |
| Gypsum                                      | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Hafnium                                     | F                                     | 720                                           | 1500                                                      | AAS                                        |
| Heptachlor                                  | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Heptane ( <i>n</i> -heptane)                | CT                                    | 4                                             | 200                                                       | GLC                                        |
| Hexachlorocyclopentadiene                   |                                       |                                               |                                                           |                                            |
| Hexachloroethane                            | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Hexachloronaphthalene                       | F (0.8 m MCEF)                        | 30                                            | 1000                                                      | GLC (1000 cc/min only)                     |
| Hexane ( <i>n</i> -hexane)                  | CT                                    | 4                                             | 200                                                       | GLC                                        |
| 2-Hexanone (methyl butyl ketone)            | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Hexone (methyl isobutyl ketone)             | CT                                    | 10                                            | 200                                                       | GLC                                        |
| sec-Hexyl acetate                           | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Hexylene glycol                             |                                       |                                               |                                                           |                                            |
| Hydrazine                                   | I                                     | 100                                           | 1000                                                      | C                                          |
| Hydrogen bromide                            | I                                     | 100                                           | 1000                                                      | ISE (1000 cc/min only)                     |
| Hydrogen chloride                           | I                                     | 15                                            | 1000                                                      | ISE (1000 cc/min only)                     |
| Hydrogen cyanide                            | F + I (0.5 m MCEF)                    | 10                                            | 2000                                                      | ISE                                        |
|                                             | OT                                    | 1                                             | 20                                                        | LDDT                                       |
| Hydrogen fluoride                           | I                                     | 45                                            | 1500                                                      | ISE (1500 cc/min only)                     |
| Hydrogen selenide                           | I                                     | 100                                           | 1000                                                      | AAS                                        |
| Hydrogen sulphide                           | I                                     | 30                                            | 2000                                                      | C                                          |
|                                             | OT                                    | 1                                             | 20                                                        | LDDT                                       |

|                                                   |                |                                      |      |                        |
|---------------------------------------------------|----------------|--------------------------------------|------|------------------------|
| Hydroquinone                                      | I              | 75                                   | 1000 | C                      |
| Indium and compounds (as In)                      | F (0.8 m MCEF) | 300                                  | 1500 | C                      |
| Iodine                                            | I              | 15                                   | 1000 | C                      |
| Iron oxide fume (NOC)                             | F (0.8 m MCEF) | 30                                   | 1500 | AAS                    |
| Iron pentacarbonyl                                | F (0.8 m MCEF) | 175                                  | 1500 | AAS                    |
| Iron salts, soluble (as Fe)                       | F (0.8 m MCEF) | 4                                    | 1500 | AAS                    |
| Isoamyl acetate                                   | CT             | 10                                   | 200  | GLC                    |
| Isoamyl alcohol                                   | CT             | 10                                   | 200  | GLC                    |
| Isobutyl acetate                                  | CT             | 10                                   | 200  | GLC                    |
| Isobutyl alcohol                                  | CT             | 10                                   | 200  | GLC                    |
| Isophorone                                        | CT             | 12                                   | 200  | GLC                    |
| Isopropyl acetate                                 | CT             | 9                                    | 200  | GLC                    |
| Isopropyl alcohol                                 | CT             | 3                                    | 200  | GLC                    |
| Isopropylamine                                    | I              | 100                                  | 1000 | GLC                    |
| Isopropyl ether                                   | CT             | 3                                    | 50   | GLC                    |
| Isopropyl glycidyl ether                          | CT             | 10                                   | 200  | GLC                    |
| Kaolin                                            | F              |                                      |      | G (nuisance dust)      |
| Ketene                                            | I              | 50                                   | 1000 | C                      |
| Lead, inorg., fumes and dusts (as Pb)             | F (0.8 m MCEF) | 100                                  | 4000 | AAS                    |
| Limestone                                         | F              |                                      |      | G (nuisance dust)      |
| Lindane                                           | F + 1          | 90                                   | 1500 | GLC                    |
| Lithium hydride                                   | F (0.8 m MCEF) | 720                                  | 1500 | AAS                    |
| LPG (liquefied petroleum gas)                     | M              | direct reading combustible gas meter |      |                        |
| Magnesite                                         | F              |                                      |      | G (nuisance dust)      |
| Magnesium oxide fume (as Mg)                      | F (0.8 m MCEF) | 150                                  | 1500 | AAS                    |
| Malathion                                         | F (GF)         | 120                                  | 1000 | GLC                    |
|                                                   | I              |                                      |      |                        |
| Manganese and compounds (as Mn)                   | F (0.8 m MCEF) | 22.5                                 | 1500 | AAS (1500 cc/min only) |
| Manganese cyclopentadienyl tricarbonyl (as Mn)    | F (0.8 m MCEF) | 25                                   | 1500 | AAS                    |
| Marble/calcium carbonate                          | F              |                                      |      | G (nuisance dust)      |
| Mercury (alkyl compounds) (as Hg)                 | OT             | 3                                    | 50   | AAS (chromosorb)       |
| Mesityl oxide                                     | CT             | 10                                   | 200  | GLC                    |
| Methanethiol, see Methyl mercaptan                |                |                                      |      |                        |
| Methoxychlor                                      | I              | 100                                  | 1000 | GLC                    |
| 2-Methoxyethanol (methyl cellosolve)              | CT             | 50                                   | 1000 | GLC                    |
| Methyl acetate                                    | CT             | 7                                    | 200  | GLC                    |
| Methyl acetylene (propyne)                        | CT             | 2                                    | 50   | GLC                    |
| Methyl acetylene propadiene mixture               | CT             | 2                                    | 50   | GLC                    |
| Methyl acrylate                                   | CT             | 5                                    | 200  | GLC                    |
| Methylal (dimethoxymethane)                       | CT             | 2                                    | 200  | GLC                    |
| Methyl alcohol (methanol)                         | ST             | 3                                    | 50   | GLC                    |
| Methylamine                                       | I              | 50                                   | 2000 | C                      |
| Methyl amyl alcohol, see Methyl isobutyl carbinol |                |                                      |      |                        |
| Methyl <i>n</i> -amyl ketone (2-heptanone)        | CT             | 10                                   | 200  | GLC                    |

**Table 10.30 Cont'd**

| <i>Substance</i>                                                               | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|--------------------------------------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Methyl bromide                                                                 | CT                                    | 11                                            | 1000                                                      | GLC (2 large charcoal tubes in series)     |
| Methyl butyl ketone, <i>see</i> 2-Hexanone                                     |                                       |                                               |                                                           |                                            |
| Methyl cellosolve, <i>see</i> 2-Methoxyethanol                                 |                                       |                                               |                                                           |                                            |
| Methyl cellosolve acetate, <i>see</i> Ethylene glycol monomethyl ether acetate |                                       |                                               |                                                           |                                            |
| Methyl chloroform (1,1,1-trichloroethane)                                      | CT                                    | 6                                             | 200                                                       | GLC                                        |
| Methylcyclohexane                                                              | CT                                    | 4                                             | 200                                                       | GLC (for methylcyclohexane)                |
| Methylcyclohexanol                                                             | CT                                    | 10                                            | 200                                                       | GLC                                        |
| <i>o</i> -Methylcyclohexanone                                                  | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Methylene bisphenyl isocyanate (MDI)                                           | I                                     | 20                                            | 1000                                                      | C                                          |
| Methylene chloride (dichloromethane)                                           | CT                                    | 5                                             | 1000                                                      | GLC                                        |
| 4,4'-Methylene bis (2-chloraniline) (MOCA)                                     | ST                                    | 3                                             | 500                                                       | GLC (use prefilter)                        |
| Methyl ethyl ketone (MEK), <i>see</i> 2-Butanone                               |                                       |                                               |                                                           |                                            |
| Methyl formate                                                                 | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Methyl iodide                                                                  | CT                                    | 50                                            | 1000                                                      | GLC                                        |
| Methyl isoamyl ketone                                                          | CT                                    | 5                                             | 200                                                       | GLC                                        |
| Methyl isobutyl carbinol                                                       | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Methyl isobutyl ketone, <i>see</i> Hexone                                      |                                       |                                               |                                                           |                                            |
| Methyl mercaptan                                                               | CT                                    | 15                                            | 1000                                                      | GLC                                        |
|                                                                                | I                                     | 30                                            | 2000                                                      | C                                          |
| Methyl methacrylate                                                            | CT                                    | 5                                             | 200                                                       | GLC                                        |
| Methyl parathion                                                               | I                                     | 50                                            | 2800                                                      | GLC                                        |
| Methyl propyl ketone, <i>see</i> 2-Pentanone                                   |                                       |                                               |                                                           |                                            |
| $\alpha$ -Methyl styrene                                                       | CT                                    | 3                                             | 200                                                       | GLC                                        |
| Molybdenum (as Mo)                                                             |                                       |                                               |                                                           |                                            |
| soluble compounds                                                              | F (0.8 m MCEF)                        | 90                                            | 1500                                                      | AAS                                        |
| insoluble compounds                                                            | F (0.8 m MCEF)                        | 90                                            | 1500                                                      | AAS                                        |
| Monomethyl aniline                                                             | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Monomethyl hydrazine                                                           | I                                     | 22.5                                          | 1500                                                      | C                                          |
| Morpholine                                                                     | ST                                    | 20                                            | 200                                                       | GLC                                        |
| Naphtha (coal tar)                                                             | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Naphthalene                                                                    | CT                                    | 200                                           | 1000                                                      | GLC                                        |
| $\beta$ -Naphthylamine                                                         |                                       |                                               |                                                           |                                            |
| Nickel carbonyl                                                                | I                                     | 200                                           | 2000                                                      | AAS                                        |
| Nickel, metal                                                                  |                                       |                                               |                                                           |                                            |
| Nickel, soluble compounds (as Ni)                                              | F (0.8 m MCEF)                        | 90                                            | 1500                                                      | AAS                                        |
| Nicotine                                                                       | OT                                    | 100                                           | 1000                                                      | GLC (XAD-2 resin tube)                     |
| Nitric acid                                                                    | I                                     | 200                                           | 2800                                                      | C (2800 cc/min only)                       |

|                                                                          |                |     |      |                                 |
|--------------------------------------------------------------------------|----------------|-----|------|---------------------------------|
| Nitric oxide                                                             | OT             | 1   | 20   | C (LDDT)                        |
|                                                                          |                | 1   | 50   | (MOL sieve tube)                |
| <i>p</i> -Nitroaniline                                                   | ST             | 15  | 1000 | GLC                             |
| Nitrobenzene                                                             | ST             | 50  | 1000 | GLC                             |
| <i>p</i> -Nitrochlorobenzene                                             | ST             | 50  | 1000 | GLC                             |
| Nitroethane                                                              | CT             | 10  | 200  | GLC                             |
| Nitrogen dioxide                                                         | OT             | 1   | 20   | (LDDT)                          |
|                                                                          | OT             | 1   | 50   | (MOL sieve tube)                |
|                                                                          | I              | 10  | 4000 | C                               |
| Nitrogen trifluoride                                                     | P              |     |      | PC                              |
| Nitroglycerine                                                           | OT             | 15  | 1000 | GLC (Tenax tube)                |
| Nitromethane                                                             | CT             | 10  | 200  | GLC                             |
| 1-Nitropropane                                                           | CT             | 10  | 200  | GLC                             |
| 2-Nitropropane                                                           | CT             | 10  | 200  | GLC                             |
| Nitrotoluene                                                             | ST             | 20  | 200  | GLC                             |
| Nitrotrichloromethane, see Chloropicrin                                  |                |     |      |                                 |
| Octachloronaphthalene                                                    | F (0.8 m MCEF) | 30  | 1000 | GLC                             |
| Octane                                                                   | CT             | 4   | 200  | GLC                             |
| Oil mist, mineral                                                        | F (0.8 m MCEF) | 100 | 1500 | C (fluor. spect.)               |
| Ozone                                                                    | I              | 45  | 1000 | C                               |
| Paraffin wax fume                                                        | F (SM)         | 200 | 2000 | G                               |
| Paraquat, respirable sizes                                               | F (0.8 m MCEF) | 150 | 1500 | C                               |
| Parathion                                                                | I              | 25  | 1500 | GLC                             |
|                                                                          | F (GF)         | 120 | 1500 | GLC                             |
| Particulate polycyclic aromatic hydrocarbons (PPAH), as benzene solubles | F (0.8 m SM)   | 720 | 1500 | G (use GF prefilter)            |
| Pentachloronaphthalene                                                   | F + I (GF)     | 250 | 1500 | GLC                             |
| Pentachlorophenol                                                        | F (0.8 m MCEF) | 150 | 1500 | GLC                             |
| Pentaerythritol                                                          | F              |     |      | G (nuisance dust)               |
| Pentane                                                                  | CT             | 2   | 50   | GLC                             |
| 2-Pentanone                                                              | CT             | 10  | 200  | GLC                             |
| Perchloroethylene                                                        | CT             | 1   | 200  | GLC (10 min allowed at 300 ppm) |
| Perchloromethyl mercaptan                                                | CT             | 30  | 200  | GLC                             |
| Perchloryl fluoride                                                      | I              | 30  | 1000 | ISE                             |
| Petroleum distillates (naphtha)                                          |                |     |      |                                 |
| Phenol                                                                   | I              | 100 | 1000 | GLC                             |
| <i>p</i> -Phenylene diamine                                              | I              | 101 | 1000 | C                               |
| Phenyl ether (vapour)                                                    | CT             | 10  | 200  | GLC                             |
| Phenyl ether–diphenyl mixture (vapour)                                   | ST             | 10  | 200  | GLC                             |
| Phenylethylene, see Styrene, monomer                                     |                |     |      |                                 |
| Phenyl glycidyl ether                                                    | CT             | 50  | 1000 | GLC                             |
| Phenylhydrazine                                                          | I              | 100 | 1000 | C                               |
| Phosdrin (Mevinphos®)                                                    | I              | 100 | 1000 | GLC                             |
| Phosgene (carbonyl chloride)                                             | I              | 25  | 1000 | C                               |

Table 10.30 Cont'd

| <i>Substance</i>                                          | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|-----------------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Phosphine                                                 | F (0.8 m MCEF)                        | 5                                             | 50                                                        | C (GF prefilter)                           |
| Phosphoric acid                                           | F (0.8 m MCEF)                        | 15                                            | 1500                                                      | C (four 2 hr samples)                      |
| Phosphorus (yellow)                                       |                                       |                                               |                                                           |                                            |
| Phosphorus pentachloride                                  | I                                     | 100                                           | 1000                                                      | C                                          |
|                                                           |                                       |                                               |                                                           | ISE                                        |
| Phosphorus trichloride                                    | I                                     | 100                                           | 1000                                                      | C                                          |
|                                                           |                                       |                                               |                                                           | ISE                                        |
| Phthalic anhydride                                        | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
| Picric acid                                               |                                       |                                               |                                                           |                                            |
| Pival® (2-pivalyl-1,3-indandione)                         | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Plaster of Paris                                          | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Platinum, soluble salts (as Pt)                           | F (0.8 m MCEF)                        | 720                                           | 1500                                                      | AAS                                        |
| Polychlorobiphenyls, see Chlorodiphenyls                  |                                       |                                               |                                                           |                                            |
| Polytetrafluoroethylene decomposition products            |                                       |                                               |                                                           |                                            |
| Propane                                                   |                                       |                                               |                                                           | see Fluoride procedure                     |
| Propargyl alcohol                                         | CT                                    | 30                                            | 200                                                       | GLC                                        |
| <i>n</i> -Propyl acetate                                  | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Propyl alcohol                                            | CT                                    | 10                                            | 200                                                       | GLC                                        |
| <i>n</i> -Propyl nitrate                                  | CT                                    | 70                                            | 1000                                                      | GLC                                        |
| Propylene dichloride (1,2-dichloropropane)                | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Propylene glycol monomethyl ether                         | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Propylene oxide                                           | CT                                    | 5                                             | 200                                                       | GLC                                        |
| Propyne, see Methyl acetylene                             |                                       |                                               |                                                           |                                            |
| Pyrethrum                                                 | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Pyridine                                                  | CT                                    | 100                                           | 1000                                                      | GLC                                        |
| Quinone                                                   | I                                     | 100                                           | 1000                                                      | C                                          |
| RDX                                                       | F (0.8 m MCEF)                        | 150                                           | 1500                                                      | UV                                         |
| Rhodium (as Rh)                                           |                                       |                                               |                                                           |                                            |
| metal fume and dusts                                      | F (0.8 m MCEF)                        | 720                                           | 1500                                                      | AAS                                        |
| soluble salts                                             | F (0.8 m MCEF)                        | 370                                           | 1500                                                      | AAS                                        |
| Ronnel                                                    | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Rosin core solder pyrolysis products<br>(as formaldehyde) | I                                     | 25                                            | 1000                                                      | C                                          |
| Rotenone (commercial)                                     | I                                     | 60                                            | 1000                                                      | UV                                         |
| Rouge                                                     | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Selenium compounds (as Se)                                | F (0.8 m MCEF)                        | 360                                           | 1500                                                      | AAS                                        |
| Selenium hexafluoride (as Se)                             | I                                     | 60                                            | 1000                                                      | AAS                                        |
| Sevin® (see carbaryl)                                     |                                       |                                               |                                                           |                                            |
| Silica                                                    |                                       |                                               |                                                           |                                            |
| respirable                                                | F (5 m PVC)                           | 816                                           | 1700                                                      | (cyclone, X-ray diffraction)               |
| total                                                     |                                       |                                               |                                                           |                                            |

|                                               |                    |     |      |                        |
|-----------------------------------------------|--------------------|-----|------|------------------------|
| Silicon                                       | F (SM, 1.2, 25)    |     |      | G (nuisance dust)      |
| Silicon carbide                               | F                  |     |      | G (nuisance dust)      |
| Silver, metal and soluble compounds (as Ag)   | F (0.8 m MCEF)     | 45  | 1500 |                        |
| Sodium fluoroacetate                          |                    |     |      |                        |
| Sodium hydroxide                              | I                  | 350 | 1000 | C (for titration)      |
| Starch                                        | F                  |     |      | G (nuisance dust)      |
| Stibine                                       | CT                 | 100 | 200  | AAS                    |
|                                               |                    |     |      | C                      |
| Stoddard solvent                              | CT                 | 3   | 200  | GLC                    |
| Strychnine                                    | F (0.8 m MCEF)     | 360 | 1500 | UV                     |
| Styrene, monomer (phenylethylene)             | CT                 | 1   | 200  | GLC                    |
| Succinaldehyde, see Glutaraldehyde            |                    |     |      |                        |
| Sucrose                                       | F                  |     |      | G (nuisance dust)      |
| Sulphur dioxide                               | OT                 | 1   | 20   | LDDT                   |
|                                               | F + I (0.8 m MCEF) | 100 | 2000 | C (titration)          |
|                                               | P                  |     |      | PL                     |
| Sulphur hexafluoride                          | I                  | 15  | 1000 | UV                     |
| Sulphuric acid                                | F (0.8 m MCEF)     | 10  | 1500 | C (titration)          |
| Sulphur monochloride                          | I                  | 15  | 1000 | ISE                    |
| Sulphuryl fluoride                            | I                  | 15  | 1000 | GLC                    |
| 2,4,5-T                                       | I                  | 100 | 1000 | GLC                    |
| Tantalum                                      | F (0.8 m MCEF)     | 720 | 1500 | AAS                    |
| TEDP                                          | I                  | 100 | 1000 | GLC                    |
| Teflon® decomposition products                |                    |     |      | see Fluoride procedure |
| Tellurium and compounds (as Te)               | F (0.8 m MCEF)     | 670 | 1500 | AAS                    |
| Tellurium hexafluoride (as Te)                | CT                 | 360 | 1000 | AAS (MCEF prefilter)   |
| TEPP                                          | I                  | 100 | 1000 | GLC                    |
| Terphenyls                                    | F (0.8 m MCEF)     | 15  | 1000 | GLC                    |
| 1,1,1,2-Tetrachloro 2,2-Difluoroethane        | CT                 | 2   | 35   | GLC                    |
| 1,1,2,2-Tetrachloro 1,2-Difluoroethane        | CT                 | 2   | 50   | GLC                    |
| 1,1,2,2-Tetrachloroethane                     | CT                 | 10  | 200  | GLC                    |
| Tetrachloroethylene, see Perchloroethylene    |                    |     |      |                        |
| Tetrachloromethane, see Carbon tetrachloride  |                    |     |      |                        |
| Tetrachloronaphthalene                        | F + I (GF)         | 100 | 1300 | GLC                    |
| Tetraethyl lead (as Pb)                       | CT                 | 60  | 1000 | AAS                    |
|                                               | F + I (0.8 m MCEF) | 60  | 2000 | C                      |
| Tetrahydrofuran                               | CT                 | 9   | 200  | GLC                    |
| Tetramethyl lead (as Pb)                      | CT                 | 60  | 1000 | AAS                    |
|                                               | F + I (0.8 m MCEF) | 60  | 2000 | C                      |
| Tetramethyl succinonitrile                    | CT                 | 50  | 1000 | GLC                    |
| Tetranitromethane                             | I                  | 250 | 1000 | GLC                    |
| Tetryl (2,4,6-trinitrophenylmethyl nitramine) | F (0.8 m MCEF)     | 100 | 1500 | C                      |
|                                               | F (0.8 m MCEF)     | 540 | 1500 | AAS                    |
| Thallium, soluble compounds (as TI)           | F (0.8 m MCEF)     | 180 | 1500 | AAS                    |
| Thiram                                        | F (0.8 m MCEF)     | 180 | 1500 | C                      |

**Table 10.30 Cont'd**

| <i>Substance</i>                                                               | <i>Sampling method</i> <sup>(1)</sup> | <i>Min. sample size</i> <sup>(2)</sup><br>(l) | <i>Suggested max. sample rate</i> <sup>(3)</sup> (ml/min) | <i>Analytical technique</i> <sup>(4)</sup> |
|--------------------------------------------------------------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------------------|--------------------------------------------|
| Tin, inorganic compounds, except SnH <sub>4</sub> and SnO <sub>2</sub> (as Sn) | F (0.8 m MCEF)                        | 240                                           | 1000                                                      | AAS                                        |
| Tin, organic compounds (as Sn)                                                 |                                       |                                               |                                                           |                                            |
| Tin oxide (as Sn)                                                              | F                                     |                                               |                                                           | G (nuisance dust)                          |
| Titanium dioxide (as Ti)                                                       | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | AAS (nuisance dust)                        |
| Toluene (toluol)                                                               | CT                                    | 2                                             | 1000                                                      | GLC (10 min allowed at 500 ppm)            |
| Toluene-2,4-diisocyanate (TDI)                                                 | I                                     | 20                                            | 2000                                                      | C                                          |
| o-Toluidine                                                                    | ST                                    | 50                                            | 1000                                                      | GLC                                        |
| Toxaphene, see Chlorinated camphene                                            |                                       |                                               |                                                           |                                            |
| Tributyl phosphate                                                             | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
| 1,1,1-Trichloroethane, see Methyl chloroform                                   |                                       |                                               |                                                           |                                            |
| 1,1,2-Trichloroethane                                                          | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Trichloroethylene                                                              | CT                                    | 10                                            | 1000                                                      | GLC (10 min allowed at 300 ppm)            |
| Trichloromethane, see Chloroform                                               |                                       |                                               |                                                           |                                            |
| Trichloronaphthalene                                                           | F + I (GF)                            | 100                                           | 1300                                                      | GLC                                        |
| 1,2,3-Trichloropropane                                                         | CT                                    | 10                                            | 200                                                       | GLC                                        |
| 1,1,2-Trichloro 1,2,2-Trifluoroethane                                          | CT                                    | 1.5                                           | 50                                                        | GLC                                        |
| Triethylamine                                                                  | I                                     | 100                                           | 1000                                                      | GLC                                        |
| Trifluoromonobromomethane                                                      | CT                                    | 1                                             | 50                                                        | GLC (2 charcoal tubes)                     |
| Trimethyl benzene                                                              | CT                                    | 5                                             | 200                                                       | GLC                                        |
| 2,4,6-Trinitrophenol, see Picric acid                                          |                                       |                                               |                                                           |                                            |
| 2,4,6-Trinitrophenyl-methylnitramine, see Tetryl                               |                                       |                                               |                                                           |                                            |
| 2,4,6-Trinitrotoluene (TNT)                                                    | F (0.8 m MCEF)                        | 360                                           | 1500                                                      | C                                          |
| Triorthocresyl phosphate                                                       | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
| Triphenyl phosphate                                                            | F (0.8 m MCEF)                        | 100                                           | 1500                                                      | GLC                                        |
| Tungsten and compounds (as W)                                                  |                                       |                                               |                                                           |                                            |
| soluble                                                                        |                                       |                                               |                                                           |                                            |
| insoluble                                                                      |                                       |                                               |                                                           |                                            |
| Turpentine                                                                     | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Uranium, natural (as U)                                                        |                                       |                                               |                                                           |                                            |
| soluble                                                                        | F (0.8 m MCEF)                        | 45                                            | 1500                                                      | (fluorometric)                             |
| insoluble compounds                                                            | F (0.8 m MCEF)                        | 45                                            | 1500                                                      | (fluorometric)                             |
| Vanadium (V <sub>2</sub> O <sub>5</sub> ) (as V)                               |                                       |                                               |                                                           |                                            |
| dust                                                                           | F (0.8 m MCEF)                        | 25                                            | 1700                                                      | AAS                                        |
| fume                                                                           |                                       |                                               |                                                           |                                            |
| Vinyl acetate                                                                  | CT                                    | 10                                            | 200                                                       | GLC                                        |
| Vinyl benzene, see Styrene                                                     |                                       |                                               |                                                           |                                            |
| Vinyl chloride                                                                 | CT                                    | 5                                             | 50                                                        | GLC (use 2 tubes)                          |
|                                                                                | OT                                    | 1                                             | 20                                                        | LDDT                                       |

|                                                     |                |     |      |                              |
|-----------------------------------------------------|----------------|-----|------|------------------------------|
| Vinyl cyanide, <i>see</i> Acrylonitrile             |                |     |      |                              |
| Vinylidene chloride                                 |                |     |      |                              |
| Vinyl toluene                                       | CT             | 10  | 200  | GLC                          |
| VM and P naphtha                                    |                |     |      |                              |
| Warfarin                                            |                |     |      |                              |
| Welding fumes (total particulate) (NOC)             | F (0.8 m MCEF) | 720 | 1500 | G                            |
| Xylene ( <i>o</i> -, <i>m</i> -, <i>p</i> -isomers) | CT             | 12  | 1000 | GLC                          |
| Xylidene                                            | ST             | 20  | 200  | GLC                          |
| Yttrium                                             | F (0.8 m MCEF) | 500 | 1500 | AAS                          |
| Zinc chloride fume                                  | F (0.8 m MCEF) | 25  | 1500 | AAS                          |
| Zinc oxide fume                                     | F (0.8 m MCEF) | 360 | 1500 | AAS (also X-ray diffraction) |
|                                                     | F (PVC)        |     |      |                              |
| Zinc stearate                                       | F              |     |      | G (nuisance dust)            |
| Zirconium compounds (as Zr)                         | F (0.8 m MCEF) | 720 | 1500 | AAS                          |

Based on *Sampling and Analytical Guide for Airborne Health Hazards*, Du Pont Company, Applied Technology Division.

<sup>(1)</sup> *Sampling methods*

|       |                                                                       |
|-------|-----------------------------------------------------------------------|
| AT    | Alumina tube                                                          |
| CT    | Charcoal tube or PRO-TEK™ organic vapour                              |
| F     | Filter                                                                |
| F + I | Impinger preceded by filter                                           |
| GF    | Glass fibre filter                                                    |
| I     | Impinger or fritted bubbler                                           |
| M     | Miscellaneous sampler (dosimeter etc.)                                |
| MCEF  | Mixed cellulose ester membranes filter                                |
| OT    | Other tubes (long duration detector tubes, porous polymer tubes etc.) |
| P     | PRO-TEK™ Colorimetric Air Monitoring Badge System                     |
| PVC   | Polyvinyl chloride filter                                             |
| SM    | Silver membrane filter                                                |
| ST    | Silica gel tube                                                       |

<sup>(2)</sup> The minimum air sample (litres) that will provide enough of the substance for the most accurate analysis at the TLV concentrations using the analytical procedures listed.

<sup>(3)</sup> The maximum flowrate recommended for the given collection method. Sampling may be done at lower rates as long as minimum sample size is met.

<sup>(4)</sup> *Analytical technique*

|      |                                               |
|------|-----------------------------------------------|
| AAS  | Atomic adsorption spectroscopy                |
| C    | Colorimetric                                  |
| G    | Gravimetric                                   |
| GLC  | Gas-liquid chromatography                     |
| ISE  | Ion-specific electrode                        |
| LDDT | Long-duration detector tubes                  |
| PC   | PRO-TEK™ PT <sub>3</sub> Colorimetric Readout |
| UV   | Ultraviolet                                   |



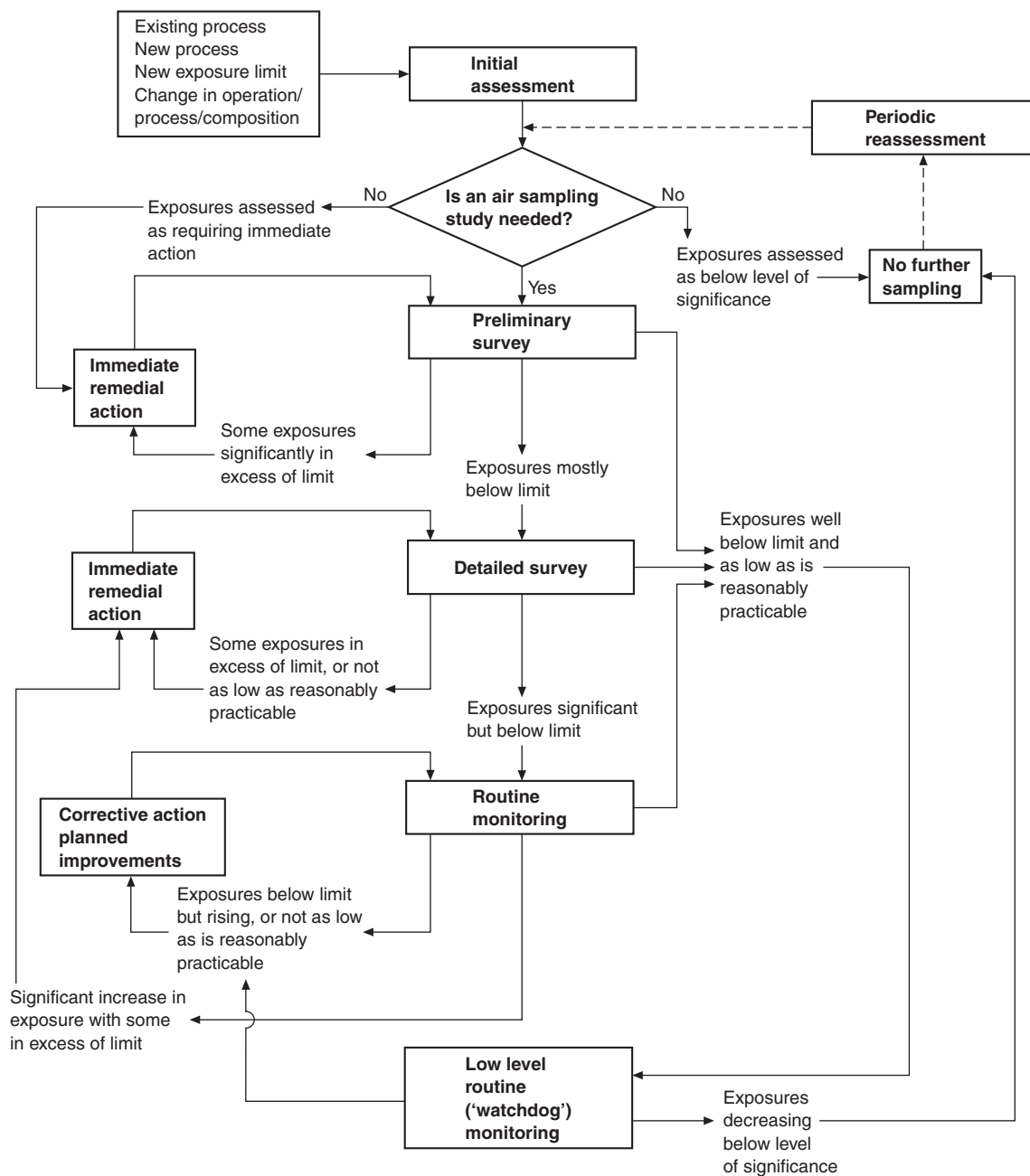


**Figure 10.1** Monitoring strategies flow diagram

**Table 10.31 Values for the range**

| <i>Number of results</i> | <i>k</i> |
|--------------------------|----------|
| 32                       | 0        |
| 10–31                    | 0.1      |
| 6–9                      | 0.2      |
| 5                        | 0.3      |
| 4                        | 0.4      |
| 3                        | 0.8      |
| 2                        | 0.9      |

**Table 10.32 Recommended guidance for routine monitoring**

| <i>Survey</i> | <i>Results</i>                                                                                                                                                                                     | <i>Action</i>                                                                                                                                                                                                                                                                             |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Preliminary   | All $<0.1 \times \text{OEL}^{(1)}$<br>0.1–1.5 $\times \text{OEL}$<br>Some $>1.5 \times \text{OEL}$                                                                                                 | None if exposures are as low as reasonably practical.<br>Investigate and carry out a more detailed survey.<br>Investigate, take remedial action and repeat survey.                                                                                                                        |
| Detailed      | All $<0.25 \times \text{OEL}$<br>$\leq 1.25 \times \text{OEL}$<br>Arithmetic mean $<0.5 \times \text{OEL}$<br>Mean $>0.5 \times \text{OEL}$ (or with individual results scattered above the limit) | None if exposure is as low as reasonably practical.<br>Investigate, take remedial action and repeat survey.<br>Consider routine monitoring and the appropriate frequency.<br>Investigate, assess control measures, improve where possible, repeat survey and consider routine monitoring. |
| Routine       | All<br><br>Differ significantly from previous survey                                                                                                                                               | Check values, mean, range, etc. Is there compliance with OEL and if so what is confidence?<br>Investigate, consider remedial action detailed survey or change protocols.                                                                                                                  |

<sup>(1)</sup> Higher values can be used if standard is based on nuisance or odour and there are no known effects of the maximum exposure concentration measured.

## Pollution monitoring strategies in incident investigation

Industrial accidents involving hazardous chemicals include release of gas or vapour (including deposition to land), fire, explosion, spillages to land, and discharges to water courses (including surface waters, ground water, spring waters, saline waters, estuaries, potable waters, industrial waste waters). Fires in storage facilities housing even apparently non-toxic chemicals such as plastics can have an ecological impact because of plastic components or their pyrolytic breakdown products, e.g. PAHs, or combustion products (Table 5.48).

In such accidents it may be imperative to determine:

- the severity of the incident;
- those chemicals that may have entered the environment;
- whether long-term problems are posed.

Personal safety, e.g. during the collection of samples for accident investigation purposes is the joint responsibility of employers and employees, e.g. sampling at heights or in deep or fast-flowing waters or close to fires. For fires, the distance downwind for sampling will be dictated by the scale of the disaster as illustrated by Table 10.33 whereas for releases not involving a fire the sampling points will be dictated by the gas, i.e. whether lighter or heavier than air.

**Table 10.33 Downwind distances to sample based on size of fire**

| <i>Scale of fire</i> | <i>Sample distances</i>                                      |
|----------------------|--------------------------------------------------------------|
| Major                | 100 m, 350 m, 700 m, 1.25 km, 2.30 km, 4.25 km, 15 km, 50 km |
| Large                | 50 m, 180 m, 350 m, 600 m, 1 km, 2 km, 7.5 km, 25 km         |
| Medium               | 20 m, 70 m, 250 m, 850 m, 3 km, 10 km                        |
| Small                | 5 m, 20 m, 60 m, 200 m, 750 m, 2.5 km                        |
| Minor                | 2 m, 10 m, 25 m, 85 m, 300 m, 1 km                           |

For releases to land, influencing factors include:

duration and extent of release;  
type of release (liquid or solid);  
hydrogeology;  
soil permeability;  
soil vulnerability;  
land use;  
screening techniques;  
levels and characteristics of historic contamination;  
depth to take sample.

The aims of sampling are to establish whether contaminants are present, their distribution and concentrations. Commonly-used sampling regimes include square grid, stratified random or simple random techniques. Evenly-spaced sampling points may be appropriate if the contamination is visible otherwise judgement is required based on whether the land slopes or is flat. Samples are also taken near to the point of release.

**Table 10.34 Data to record during accident investigation**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Information about the accident, e.g. date, time, magnitude and nature of release.<br/> Speed of response/dates of actions.<br/> Sample numbers and history, e.g. date, time of collection.<br/> Ecosystems, structures and individuals potentially affected.<br/> Number of samples collected and sampling pattern.<br/> Sample quality and sample programme.<br/> Resources.<br/> Analytical techniques (including method, accuracy, precision, reproducibility, robustness, limits of detection).<br/> Sample package, storage, transport and security to ensure integrity.<br/> List of sample equipment and calibration record.<br/> Names and training records of staff involved in sampling and analysis, or details of contract analysts and any quality standards/accreditation schemes with which they comply.<br/> Physical and chemical properties of the chemical (see Chapter 12).<br/> The form in which it was released, and subsequent forms.<br/> Characteristics of the receiving ecosystem (e.g. solid type, ground water, drinking water, fish/shellfish water, bathing water) and how it migrates from one environment to another.<br/> Meteorology during and after the accident.<br/> Topography.<br/> Environmental, health, or safety properties of the pollutants including their acute and chronic effects and any synergistic effects.<br/> Visible environmental impact on site.<br/> Recorded quality of ecosystem prior to accident.<br/> Site plan with marked release points, sample points, detailed dimensions.<br/> Temperature of chemicals released.</p> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Generally, sampling of waterways should be at the fastest flowing part of the stream/river, usually mid-depth unless the contaminant is less dense than water and could float, or is more dense and could accumulate near the river bed. For lakes representative samples should be taken near to the inflow, outflow and other locations. If two phases are present both may require sampling. Sample preservation by refrigeration, pH adjustment, elimination of light, filtration, and extraction may be important.

Table 10.34 summarizes the information to be recorded during an investigation. (A code of practice for the identification of potentially contaminated land and its investigation is given in British Standard DD 175/1988.) Consideration should be given to the application of appropriate quality control and quality assurance procedures such as those advocated by 'good laboratory practice' or ISO 17025 to ensure the sampling, the analysis and interpretation/reporting of data are robust since results will dictate action and may be subject to scrutiny by third parties. Duplicate samples may need to be retained for disclosure to third parties. There may be legal requirements to notify results to relevant authorities.

# Radioactive chemicals

The main chemical elements are listed in Chapter 18. Each comprises a nucleus of positively-charged protons and neutral neutrons orbited by negative electrons. The mass number  $A$  is given by

$$A = Z + N$$

where  $Z$  is the number of protons, or atomic number

$N$  is the number of neutrons.

Atoms with the same value of  $Z$  but different values of  $A$  are isotopes (Table 11.1). Many isotopes are stable but others are naturally or artificially radioactive, i.e. their atomic nuclei disintegrate, emitting particles or radiation. This changes the nuclear structure of the atom and often results in the production of a different element.

**Table 11.1 Nuclear composition of selected istopes**

| <i>Element</i> | <i>Symbol</i>            | <i>Atomic number</i> | <i>Protons</i> | <i>Neutrons</i> | <i>Total number of protons and neutrons</i> | <i>Atomic weight</i> |
|----------------|--------------------------|----------------------|----------------|-----------------|---------------------------------------------|----------------------|
| Hydrogen       | ${}^1_1\text{H}$         | 1                    | 1              |                 | 1                                           | 1.0080               |
| (Deuterium)    | ${}^2_1\text{H}$         | 1                    | 1              | 1               | 2                                           |                      |
| Carbon         | ${}^{12}_6\text{C}$      | 6                    | 6              | 6               | 12                                          | 12.010               |
|                | ${}^{13}_6\text{C}$      | 6                    | 6              | 7               | 13                                          |                      |
|                | ${}^{14}_6\text{C}$      | 6                    | 6              | 8               | 14                                          |                      |
| Nitrogen       | ${}^{13}_7\text{N}$      | 7                    | 7              | 6               | 13                                          | 14.008               |
|                | ${}^{14}_7\text{N}$      | 7                    | 7              | 7               | 14                                          |                      |
|                | ${}^{15}_7\text{N}$      | 7                    | 7              | 8               | 15                                          |                      |
| Chlorine       | ${}^{35}_{17}\text{Cl}$  | 17                   | 17             | 18              | 35                                          | 35.457               |
|                | ${}^{37}_{17}\text{Cl}$  | 17                   | 17             | 20              | 37                                          |                      |
| Lead           | ${}^{206}_{82}\text{Pb}$ | 82                   | 82             | 124             | 206                                         | 207.21               |
|                | ${}^{207}_{82}\text{Pb}$ | 82                   | 82             | 125             | 207                                         |                      |
|                | ${}^{208}_{82}\text{Pb}$ | 82                   | 82             | 126             | 208                                         |                      |
| Uranium        | ${}^{234}_{92}\text{U}$  | 92                   | 92             | 142             | 234                                         | 238.07               |
|                | ${}^{235}_{92}\text{U}$  | 92                   | 92             | 143             | 235                                         |                      |
|                | ${}^{238}_{92}\text{U}$  | 92                   | 92             | 146             | 238                                         |                      |

Natural sources of ionizing radiation include cosmic rays and nucleides such as potassium-40, carbon-14 and isotopes of thorium and uranium which are present in rocks, earth and building materials. Industrial sources of radiation include nuclear reactors, X-ray radiography, electron microscopy, X-ray diffractors, thickness gauges, smoke detectors, electron beam welding and certain processes including chemical analysis, polymer curing, chemical/biological tracing, food and medical sterilization, and mining. The radiation source can be sealed, when the radiation can be switched off, or unsealed. Examples of the former are smoke detectors and electrical devices for producing radiation.

## Hazards

The chemistry, and hence hazards, of 'hot', or radioactive, elements parallel those of their 'cold' isotopes. However, the radiation poses additional toxicity hazards. A qualitative classification of selected isotopes in terms of toxicity is given in Table 11.2. The biological effects of ionizing radiation stem mainly from damage to individual cells following ionization of the water content. Oxidizing species, e.g. hydrogen peroxide, form together with ions and free radicals, all capable of chemical attack on important organic moieties within the cells, e.g. nucleic acids. Biological effects are influenced by the type of radiation, the dose, duration of exposure, exposed organ and route of entry. Effects on cells include death, mutation and delayed reproduction. Acute adverse effects of exposure are illustrated in Table 11.3.

**Table 11.2 Classification of isotopes according to relative radiotoxicity per unit activity**

The isotopes in each class are listed in order of increasing atomic number

|                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Very high toxicity</b> | Sr-90 + Y-90, *Pb-210 + Bi-210 (Ra D + E), Po-210, At-211, Ra-226 + 55 per cent *daughter products, Ac-227, *U-233, Pu-239, *Am-241, Cm-242.                                                                                                                                                                                                                                                                                                                                                                        |
| <b>High toxicity</b>      | Ca-45, *Fe-59, Sr-89, Y-91, Ru-106 + *Rh-106, *I-131, *Ba-140 + La-140, Ce-144 + *Pr-144, Sm-151, *Eu-154, *Tm-170, *Th-234 + *Pa-234, *natural uranium.                                                                                                                                                                                                                                                                                                                                                            |
| <b>Moderate toxicity</b>  | *Na-22, *Na-24, P-32, S-35, Cl-36, *K-42, *Sc-46, Sc-47, *Sc-48, *V-48, *Mn-52, *Mn-54, *Mn-56, Fe-55, *Co-58, *Co-60, Ni-59, *Cu-64, *Zn-65, *Ga-72, *As-74, *As-76, *Br-82, *Rb-86, *Zr-95 + *Nb-95, *Nb-95, *Mo-99, Tc-98, *Rh-105, Pd-103 + Rh-103, *Ag-105, Ag-111, Cd-109 + *Ag-109, *Sn-113, *Te-127, *Te-129, *I-132, Cs-137 + *Ba-137, *La-140, Pr-143, Pm-147, *Ho-166, *Lu-177, *Ta-182, *W-181, *Re-183, *Ir-190, *Ir-192, Pt-191, *Pt-193, *Au-196, *Au-198, *Au-199, Tl-200, Tl-202, Tl-204, *Pb-203. |
| <b>Slight toxicity</b>    | H-3, *Be-7, C-14, F-18, *Cr-51, Ge-71, *Tl-201.                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

\*Gamma-emitter.

## Types of radiation

The nature of the radioactive decay is characteristic of the element; it can be used to 'fingerprint' the substance. Decay continues until both the original element and its daughter isotopes are non-radioactive. The half-life, i.e. the time taken for half of an element's atoms to become non-radioactive, varies from millions of years for some elements to fractions of a second for others.

1.  $\alpha$ -Particles (helium nuclei, i.e. 2 neutrons plus 2 protons): on emission the original isotope degrades into an element of two atomic numbers or less, e.g. uranium 238 produces thorium 234. Such transformations are usually accompanied by  $\gamma$ -radiation or X-radiation.  $\alpha$ -Particles have a velocity about one-tenth that of light with a range in air of 3–9 cm. Because of their relatively

**Table 11.3 Effects of acute exposures to X- and  $\gamma$ -radiation**

| <i>Dose<br/>(Gy)</i> | <i>Effects</i>                                                                                                                                                                 |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <1                   | No clinical effects but small depletions in normal white cells count and in platelets likely within 2 days.                                                                    |
| 1                    | About 15% of those exposed show symptoms of loss of appetite, nausea, vomiting, fatigue etc. 1 Gy delivered to whole body or 5 Gy delivered to bone marrow produces leukaemia. |
| 2                    | Some fatalities occur.                                                                                                                                                         |
| 3.5–4                | LD <sub>50</sub> (see Ch. 5), death occurring within 30 days. Erythema (reddening of skin) within 3 weeks.                                                                     |
| 7–10                 | LD <sub>100</sub> , death occurring within 10 days.                                                                                                                            |

large size and double positive charge they do not penetrate matter very readily and are stopped by paper, cellophane, aluminium foil and even skin. If inhaled or ingested, however, absorption of  $\alpha$ -particles within tissues may cause intense local ionization.

2.  $\beta$ -Rays comprise electrons of velocity approaching that of light with a range of several metres and an energy of 0–4 MeV.  $\beta$ -Particles of <0.07 MeV do not penetrate the epidermis whereas those >2.5 MeV penetrate 1–2 cm of soft tissue. Thus  $\beta$ -emitters pose both an internal and an external radiation hazard: skin burns and malignancies can result. Once inside the body they are extremely hazardous, though less so than  $\gamma$ -rays. About 1 mm of aluminium is needed to stop these particles. Most  $\beta$ -emissions are accompanied by  $\gamma$ - or X-radiation and result in transformation into the element of one atomic number higher or lower but with the same atomic mass.

3.  $\gamma$ -Radiation is similar to, but shorter in wavelength than, X-rays and is associated with many  $\alpha$ - or  $\beta$ -radiations.  $\gamma$ -Radiation does not transform isotopes/elements. Like X-rays,  $\gamma$ -rays are very penetrating; they are capable of penetrating the whole body and thus require heavy shielding, e.g.  $\gamma$ -rays from  $^{60}\text{Co}$  penetrate 15 cm steel.

4. X-Radiation like  $\gamma$ -radiation is electromagnetic in nature. It can be emitted when  $\beta$ -particles react with atoms. More often it is electrically generated by accelerating electrons in a vacuum tube. The latter source can be switched off. X-rays are extremely penetrating and are merely attenuated by distance and shielding.

5. Neutron radiation is emitted in fission and generally not spontaneously, although a few heavy radionuclides, e.g. plutonium, undergo spontaneous fission. More often it results from bombarding beryllium atoms with an  $\alpha$ -emitter. Neutron radiation decays into protons and electrons with a half-life of about 12 min and is extremely penetrating.

The same type of radiation emitted by different isotopes may differ significantly in energy, e.g.  $\gamma$ -radiation from potassium-42 has about four times the energy of  $\gamma$ -radiation from gold-198.

Units of radiation are the becquerel (Bq), the gray (Gy) and the sievert (Sv).

## Control measures

The control of ionizing radiation is heavily regulated. Expert advice should be sought prior to introducing sources of radiation onto the premises. The general provisos for their control are that:

- All practices resulting in exposure shall be justified by the advantages produced.
- All exposures shall be as low as reasonably practicable.

The dose received shall not exceed specified limits. As with most hygiene standards these limits vary slightly between nations: local values should be consulted. Limits set within the UK are summarized in Table 11.4.

All regulatory requirements will be followed.

All incidents will be investigated and reported.

**Table 11.4 UK exposure limits (the Ionizing Radiations Regulations, 1999)**

| <i>Dose (mSv in any calendar year)</i>                                                     | <i>Employee aged 18 or over</i> | <i>Trainee under 18</i> | <i>All others</i> |
|--------------------------------------------------------------------------------------------|---------------------------------|-------------------------|-------------------|
| Whole body                                                                                 | 20*                             | 6                       | 1                 |
| Equivalent dose for the Lens of eye                                                        | 150                             | 50                      | 15                |
| Skin**                                                                                     | 500                             | 150                     | 50                |
| Arms, forearms, feet, ankles                                                               | 500                             | 150                     | 50                |
| Abdomen of women of child bearing capacity at work (in any consecutive period of 3 months) | 13***                           |                         |                   |

\* Where these limits are impracticable having regard to the nature of the work the employer may apply a dose limit of 100 mSv in any period of 5 consecutive months subject to a maximum effective dose of 50 mSv in any single calendar year, and to prior approval by the Radiation Protection Adviser, the affected employee(s), and the Health and Safety Executive.

\*\* As applied to the dose averaged over an area of 1 cm<sup>2</sup> regardless of area exposed.

\*\*\* Once an employer has been informed that an employee is pregnant the equivalent dose to a foetus should not exceed 1 mSv during the remainder of the pregnancy and significant bodily contamination of breast-feeding employees must be prevented.

In the UK, annual doses of 20 mSv, or any case of suspected overexposure, must be investigated, reported and recorded. The HSE must also be notified of any spillages of radioactive substance beyond specified amounts. Companies are obliged to monitor exposures and investigate excursions beyond action limits, and to maintain records for specified periods. Checks on surface contamination are aimed at avoiding exposure, preventing spread of contaminant, detecting failures in containment or departures from good practice, and providing data for planning further monitoring programmes.

Air monitoring will be required, e.g., when volatiles are handled in quantity, where use of radioactive isotopes has led to unacceptable workplace contamination, when processing plutonium or other transuranic elements, when handling unsealed sources in hospitals in therapeutic amounts, and in the use of 'hot' cells/reactors and critical facilities. Routine monitoring of skin, notably the hands, may be required.

Monitoring for both external and internal radiation may be required, e.g. when handling large quantities of volatile 'hot' chemicals or in the commercial manufacture of radionuclides, in natural and enriched uranium processes, in the processing of plutonium or other transuranic elements, and in uranium milling and refining. The nature of biological monitoring is influenced by the isotope: e.g., faeces, urine and breath monitoring is used for  $\alpha$ - and  $\beta$ -emitters and whole-body monitoring for  $\gamma$ -sources.

Exposure is minimized by choice of source, by duration of exposure, by distance from source (at 1 m the radiation level is reduced almost 10-fold), and by shielding. The greater the mass per unit area of shield material the greater the shielding efficiency. Whereas  $\alpha$ - and  $\beta$ -particles pose few problems (the former can be absorbed by, e.g., paper and the latter by 1 cm Perspex)  $\gamma$ - and X-rays are not completely absorbed by shield material but attenuated exponentially such that radiation emerging from the shield is given by:



$$D_t = D_0 e^{-ut}$$

where  $D_0$  is the dose without a shield

$D_t$  is the dose rate emerging from a shield of thickness  $t$

$u$  is the linear absorption coefficient of shield material.

Half-thickness values (H-TV) i.e. thickness to reduce intensity to half the incidence value, for materials commonly used as shields for selected  $\gamma$ -rays are exemplified by Table 11.5.

**Table 11.5 Approximate half-thickness values for a selection of shield materials and  $\gamma$ -emitters**

| Nuclide           | Half-life  | $\gamma$ -energy<br>(MeV) | Concrete | Steel | H-TV (cm)<br>Lead |
|-------------------|------------|---------------------------|----------|-------|-------------------|
| $^{137}\text{Cs}$ | 27 years   | 0.66                      | 4.82     | 1.63  | 0.65              |
| $^{60}\text{Co}$  | 5.24 years | 1.17–1.33                 | 6.68     | 2.08  | 1.20              |
| $^{198}\text{Au}$ | 2.7 days   | 0.41                      | 4.06     | –     | 0.33              |
| $^{192}\text{Ir}$ | 74 days    | 0.13–1.06                 | 4.32     | 1.27  | 0.60              |
| $^{226}\text{Ra}$ | 1622 years | 0.047–2.4                 | 6.86     | 2.24  | 1.66              |

Detailed precautions for handling radioactive substances will be dictated by the nature and quantity of isotope and the likely level of exposure. Thus for some materials laboratory coats and gloves may be adequate; for others a fully enclosed suit and respirator may be more appropriate. Some general precautions are listed in Table 11.6.

**Table 11.6 General control measures for work with radioactive substances**

|                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Consult experts including competent authorities (in UK the HSE must be given 28 days prior notice of specified work with ionizing radiation).                                                                                                                                                                                                                                                     |
| Conduct a risk assessment to any employee and other persons to identify measures needed to restrict exposure to ionizing radiation and to assess magnitude of risk including identifiable accidents.                                                                                                                                                                                              |
| Conduct work in designated controlled areas (e.g. in UK these are areas in which instantaneous dose rates $>7.5$ Sv/hour occur, or where employees may exceed 6 mSv annual dose limit, or where air concentration or surface contamination exceeds specified levels).                                                                                                                             |
| Provide barriers for identification and display of appropriate warning notices, e.g. Trefoil symbol.                                                                                                                                                                                                                                                                                              |
| Control exposures by engineering techniques, e.g. containment, shielding, ventilation (consider need for in-duct filters to remove contamination prior to exhausting to atmosphere), backed up by systems of work and personal protection including approved respirators where necessary.                                                                                                         |
| Use remote handling techniques where necessary.                                                                                                                                                                                                                                                                                                                                                   |
| Appoint a Radiation Protection Adviser: all staff involved with radioactive work should be adequately trained and instructed.                                                                                                                                                                                                                                                                     |
| Limit access to designated areas to classified persons (e.g. in UK persons likely to receive doses in excess of 6 mSv per year or an equivalent dose which exceeds 30% of relevant hygiene standard). Access may need to be limited by trapped keys or interlocks for high dose rate enclosures.                                                                                                  |
| Prepare as appropriate written rules for work in designated areas and appoint Radiation Protection Supervisors.                                                                                                                                                                                                                                                                                   |
| Check exposures routinely by personal dosimetry or following accidents (in the UK dosimetry services must be approved) and keep records (e.g. in UK for at least 50 years). Notify the relevant employees and authorities as appropriate. Monitor background contamination periodically using equipment that has been checked by qualified persons and keep records of levels (e.g. for 2 years). |
| Investigate accidents which may have led to persons receiving effective doses in excess of 6 mSv or an equivalent dose greater than 30% of any relevant dose limit. Investigate and report to the authorities loss of materials from accidental release to atmosphere, spillages, theft. The Regulations provide a comprehensive list of notifiable concentrations for each radionuclide isotope. |
| Provide mandatory medical surveillance for classified workers, e.g. medical examinations prior to commencement of radioactive work followed by check-ups annually or when overexposure may have occurred. (In the UK the surveillance must be undertaken by appointed doctors and records retained for at least 50 years.)                                                                        |
| Maintain high standards of personal hygiene and housekeeping.                                                                                                                                                                                                                                                                                                                                     |

**Table 11.6 Cont'd**

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Do not eat, drink, smoke, apply cosmetics or use mouth pipettes in controlled areas. Dress any wounds prior to entering the area.

Wherever practicable, store radioactive substances in sealed, properly labelled containers. Check for leaks periodically (e.g. 2-yearly intervals) and maintain records of stocks including sealed sources (e.g. for 2 years).

Carry out work over spill trays to contain leakages and use impervious work surfaces.

Decontaminate apparatus and prevent cross-contamination.

Collect waste for treatment or disposal and deal with spillages immediately.

Remove protective clothing in a changing area provided with wash basin, and lockers for clean and dirty clothing.

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# Safety by design

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Plant and equipment design are regulated by substantial legislation. In the UK this includes: The Health and Safety at Work etc. Act 1974, the Provision and Use of Work Equipment Regulations 1998, the Control of Substances Hazardous to Health Regulations 1999, the Factories Act 1961, the Electricity at Work Regulations 1989, the Fire Precautions Act 1971, together with specific legislation, e.g. the Highly Flammable Liquids and LPG Regulations 1972.

Common matters, e.g. ventilation, temperature and lighting; floor, wall and ceiling surfaces; workspace allocation; workstation design and arrangement; floors and traffic routes; safeguards against falls or being struck by a falling object; glazing; doors and gates; travelators and escalators; sanitary and washing facilities; drinking water supply; accommodation for clothing; facilities for changing, resting and meals; are all covered by the Workplace (Health, Safety and Welfare Regulations) 1992.

## Design procedures

To ensure safety consult flowsheets/engineering line diagrams and consider both the materials (raw materials storage, processing, product storage, disposal and transportation) and the process details (scale, batch vs continuous, temperature, pressure, materials of construction, monitoring, safety features, e.g. fail-safe or 'second chance' design). See Table 12.1. Subject the proposals to detailed scrutiny, as in Table 12.2 or using a HAZOP study, fault tree analysis, etc. for both the planned operation and anticipated major deviations from normal operation (Table 12.3).

A HAZOP (Hazard and Operability Study) involves a formal review of process and instrumentation diagrams by a specialist team using a structured technique, based upon key words. These comprise 'property words' and 'guide words', e.g. as in Table 12.4.

Where possible plants of intrinsically safe design are preferred, i.e. those which have been designed to be 'self-correcting' rather than those where equipment has been 'added on' to control hazards. Some characteristics of intrinsically safe plants are:

- Low inventory (small plant with less inherently hazardous materials on site).
- Substitution of hazardous materials with less dangerous chemicals.
- Attenuation of risk by using hazardous materials in the least dangerous form.
- Simplification of plant, instrumentation, operating procedures to reduce the chance of human error.
- Domino effects eliminated so that adverse events are self-terminated and do not initiate new events.
- Incorrect assembly of plant made impossible by equipment design.

**Table 12.1 Some considerations in reaction process selection and design**


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|                                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Are unstable reactions and side reactions possible, e.g. spontaneous combustion or polymerization?                                                            |
| Could poor mixing or inefficient distribution of reactants and heat sources result in undesirable side reactions, hot spots, runaway reactions, fouling, etc? |
| Can hazards from the reaction be reduced by changing the relative concentration of reactants or other operating conditions?                                   |
| Can side reactions produce toxic or explosive material, or cause dangerous fouling?                                                                           |
| Will materials absorb moisture from the air and then swell, adhere to surfaces, form toxic or corrosive liquid or gas, etc?                                   |
| What is the effect of impurities on chemical reactions and upon process mixture characteristics?                                                              |
| Are materials of construction compatible mutually and with process materials?                                                                                 |
| Can dangerous materials build up in the process, e.g. traces of combustible and non-condensable materials?                                                    |
| What are the effects of catalyst behaviour, e.g. aging, poisoning, disintegration, activation, regeneration?                                                  |
| Are inherently hazardous operations involved:                                                                                                                 |
| Vaporization and diffusion of flammable/toxic liquids or gases?                                                                                               |
| Dusting and dispersion of combustible/toxic solids?                                                                                                           |
| Spraying, misting or fogging of flammable/combustible materials or strong oxidizing agents?                                                                   |
| Mixing of flammable materials and combustible solids with strong oxidizing agents?                                                                            |
| Separation of hazardous chemicals from inerts or diluents?                                                                                                    |
| Increase in temperature and/or pressure of unstable liquids?                                                                                                  |

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The status of plant should be immediately obvious.

The tolerance should be such that small mistakes do not lead to major problems.

Leaks should be small.

Table 12.5 summarizes the application of these principles (after Kletz – see Bibliography). Where this approach is not feasible, external features of plant must ensure the minimization of unwanted consequences.

## Layout

Factory layout has a significant bearing on safety. Relevant considerations include:

Relative positions of storage and process areas; control room, laboratories and offices – i.e. areas of highest population density; switch-house; materials receipt and despatch areas; effluent treatment facilities. Spacing distances according to standard guidelines.

Need for normal and emergency access (and escape).

Security, e.g. fencing requirement, control of access.

Topography.

Tendency for flooding.

Location of public roads.

Prevailing wind direction.

Zoning of electrical equipment (Table 12.6).

Positions of neighbouring developments, housing, public roads, controlled water courses, etc.

Segregation is practised to allow for housekeeping, construction and maintenance requirements and to reduce the risk of an accident resulting in a ‘domino effect’, e.g. from a fire, explosion or toxic release. For very toxic substances, e.g. prussic acid (HCN) or tetraethyl lead, this may involve isolating the entire manufacturing operation in a separate unoccupied building or sealed-off area.

**Table 12.2 Chemical process hazard identification**

|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Materials and reaction</b>        | <p>Identify all hazardous process materials, intermediates and wastes</p> <p>Produce material information sheets for each process material</p> <p>Check the toxicity of process materials, identify short and long term effects for various modes of entry into the body and different exposure tolerance</p> <p>Identify the relationship between odour and toxicity for all process materials</p> <p>Determine the means for industrial hygiene recognition, evaluation and control</p> <p>Determine relevant physical properties of process materials under all process conditions, check source and reliability of data</p> <p>Determine the quantities and physical states of material at each stage of production, handling and storage, relate these to the danger and second-degree hazards</p> <p>Identify any hazard the product might present to transporters and public while in transit</p> <p>Consult process material supplier regarding properties, characteristics, safety in storage, handling and use</p> <p>Identify <i>all</i> possible chemical reactions, both planned and unplanned</p> <p>Determine the inter-dependence of reaction rate and variables, establish the limiting values to prevent undesirable reactions, excessive heat development etc.</p> <p>Ensure that unstable chemicals are handled so as to minimize their exposure to heat, pressure, shock and friction</p> <p>Are the construction materials compatible with each other and with the chemical process materials, under all foreseeable conditions?</p> <p>Can hazardous materials build-up in the process, e.g. traces of combustible and noncondensable materials?</p> |
| <b>General process specification</b> | <p>Are the scale, type and integration of the process correct, bearing in mind the safety and health hazards?</p> <p>Identify the major safety hazards and eliminate them, if possible</p> <p>Locate critical areas on the flow diagrams and layout drawings</p> <p>Is selection of a specific process route, or other design option, more appropriate on safety grounds?</p> <p>Can the process sequence be changed to improve the safety of the process?</p> <p>Could less hazardous materials be used?</p> <p>Are emissions of material necessary?</p> <p>Are necessary emissions discharged safely and in accordance with good practice and legislation?</p> <p>Can any unit or item be eliminated and does this improve safety, e.g. by reducing inventory or improving reliability?</p> <p>Is the process design correct?</p> <p>Are normal conditions described adequately?</p> <p>Are all relevant parameters controlled?</p> <p>Are the operations and heat transfer facilities properly designed, instrumented and controlled?</p> <p>Has scale-up of the process been carried out correctly?</p> <p>Does the process fail safe in respect of heat, pressure, fire and explosion?</p> <p>Has second chance design been used?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Spacing distances may be reduced in the light of:

explosion relief, blast-proofing, blast walls, earth banks;  
bunds, dykes;  
steam and water curtains; foam blanketing provisions;  
inter-positioning of sacrificial plant, e.g. cooling towers, unpopulated buildings;  
provision of refuges, e.g. for toxic release incidents.

Adequate distance frequently serves to mitigate the consequences of an accidental release of chemicals, e.g. a flammable liquid spillage or toxic gas escape.

Distances are recommended for zoning of electrical equipment, separation of storage from buildings etc. Distances are also proposed (on the basis of experience) to minimize the escalation

**Table 12.3 Checklist for major deviations from normal operation**


---

|                                                                                                                                                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Start-up and shutdown;                                                                                                                                                                              |
| What else, apart from normal operation, can happen?                                                                                                                                                 |
| Is suitable provision made for such events?                                                                                                                                                         |
| Can start-up and shutdown of plant, or placing of plant on hot standby, be expedited easily and safely?                                                                                             |
| Can the plant pressure or the inventory of process materials, or both, be reduced effectively and safely in a major emergency?                                                                      |
| Are the operating parameter limits which require remedial action, known and measured, e.g. temperature, pressure, flow, concentration?                                                              |
| Should plant be shutdown for any deviation beyond the operating limits?                                                                                                                             |
| Does this require the installation of alarm, trip, or both, i.e. to what extent is manual intervention expected?                                                                                    |
| Does material change phase from its state in normal operation, during the start-up, and shutdown of plant? Is this acceptable, e.g. does it involve expansion or contraction, solidification, etc.? |
| Can effluent and relief systems cope with large or abnormal discharges, during start-up, shutdown, hot standby, commissioning and fire-fighting?                                                    |
| Are adequate supplies of utilities and miscellaneous chemicals available for all activities, e.g. absorbents for spillage control?                                                                  |
| Is inert gas immediately available in all locations where it may be required urgently?                                                                                                              |
| Is there a standby supply?                                                                                                                                                                          |
| Is any material added during start-up and shutdown, which can create a hazard on contact with process or plant materials?                                                                           |
| Is the means of lighting flames, e.g. on burners and flares, safe on every occasion?                                                                                                                |

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**Table 12.4 Key words for use in HAZOP studies****Typical property words**


---

| <i>Common</i> | <i>Application-dependent</i> |
|---------------|------------------------------|
| Flow          | Viscosity                    |
| Temperature   | Flash point                  |
| Pressure      | Vapour pressure              |
| Level         | Heat transfer                |
| Concentration | Separate                     |
|               | Absorb                       |
|               | etc.                         |

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**Guide words for HAZOP studies**


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| <i>Guide words</i> | <i>Meaning</i>                            | <i>Comment</i>                                                                                                                                                                    |
|--------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NO/NOT             | The complete negation of these intentions | No part of the intentions is achieved but nothing else happens                                                                                                                    |
| MORE/LESS          | Quantitative increase or decrease         | Refer to quantities and properties such as flowrates and temperatures as well as activities like 'heat', 'react'                                                                  |
| AS WELL AS         | Qualitative increase                      | All the design and operating intentions are achieved together with some additional activity                                                                                       |
| PART OF            | Qualitative decrease                      | Only some of the intentions are achieved: some are not                                                                                                                            |
| REVERSE            | The logical opposite of the intention     | Mostly applicable to activities, e.g. reverse flow, chemical reaction. Can also be applied to substances, e.g. 'poison' instead of 'antidote', 'D' instead of 'L' optical isomers |
| OTHER THAN         | Complete substitution                     | No part of the original intention is achieved; something quite different happens                                                                                                  |

---

**Table 12.5 Features of intrinsically safe plants**

| <i>Characteristic</i>                               | <i>Examples</i>                                      |                                          |
|-----------------------------------------------------|------------------------------------------------------|------------------------------------------|
|                                                     | <i>Friendliness</i>                                  | <i>Hostility</i>                         |
| <b>Low inventory</b>                                |                                                      |                                          |
| Heat transfer                                       | Miniaturized                                         | Large                                    |
| Intermediate storage                                | Small or nil                                         | Large                                    |
| Reaction                                            | Vapour phase                                         | Liquid phase                             |
|                                                     | Tubular reactor                                      | Pot reactor                              |
| Liquids separation                                  | Centrifugal                                          | Gravity settling                         |
| <b>Substitution</b>                                 |                                                      |                                          |
| Heat transfer media                                 | Non-flammable                                        | Flammable                                |
| Solvents                                            | Non-flammable/low toxicity                           | Flammable/high toxicity                  |
| <b>Attenuation</b>                                  |                                                      |                                          |
| Liquefied gases                                     | Refrigerated                                         | Under pressure                           |
| Explosive powders                                   | Slurried                                             | Dry                                      |
| Runaway reactants                                   | Diluted                                              | Neat                                     |
| Any material                                        | Vapour, superheated liquid                           | Liquid                                   |
| Any process                                         | Low pressure                                         | High pressure/vacuum                     |
|                                                     | Moderate temperature                                 | High or very low temperature             |
| <b>Simplification</b>                               |                                                      |                                          |
|                                                     | Hazards avoided                                      | Hazards controlled by added equipment    |
|                                                     | Single stream                                        | Multistream with many crossovers         |
|                                                     | Dedicated plant                                      | Multipurpose plant                       |
| Liquid or powder transfer                           | One big plant                                        | Many small plants                        |
|                                                     | By gravity                                           | Pressurized                              |
| <b>Domino effects</b>                               |                                                      |                                          |
|                                                     | Open construction                                    | Closed buildings                         |
| Tank roof                                           | Fire breaks                                          | No fire breaks                           |
| Horizontal cylinder                                 | Weak seam                                            | Strong seam                              |
|                                                     | Pointing away from other equipment and buildings     | Pointing at other equipment or buildings |
| <b>Incorrect assembly impossible</b>                |                                                      |                                          |
| Compressor valves                                   | Non-interchangeable                                  | Interchangeable                          |
| Device for adding water to oil                      | Cannot point upstream                                | Can point upstream                       |
| <b>Obvious state</b>                                |                                                      |                                          |
|                                                     | Rising spindle valve or ball valve with fixed handle | Non-rising spindle valve                 |
|                                                     | Figure-8 plate                                       | Spade                                    |
| <b>Tolerant of maloperation or poor maintenance</b> |                                                      |                                          |
|                                                     | Continuous plant                                     | Batch plant                              |
|                                                     | Spiral-wound gasket                                  | Fibre gasket                             |
|                                                     | Expansion loop                                       | Bellows                                  |
|                                                     | Fixed pipe                                           | Hose                                     |
|                                                     | Articulated arm                                      | Hose                                     |
|                                                     | Bolted arm                                           | Quick-release coupling                   |
|                                                     | Metal                                                | Glass, plastic                           |
|                                                     | Self-sealing couplings                               | Standard couplings                       |
| <b>Low leak rate</b>                                |                                                      |                                          |
|                                                     | Spiral-wound gasket                                  | Fibre gasket                             |
|                                                     | Tubular reactor                                      | Pot reactor                              |
|                                                     | Vapour-phase reactor                                 | Liquid-phase reactor                     |

**Table 12.6 Electrical zoning**

Classification of hazard areas according to the probability of a flammable concentration of vapour occurring (to BS 5345 Part 1)

|                  |                                                                                                                                          |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Zone 0</b>    | Area in which an explosive gas–air mixture is continuously present, or present for long periods                                          |
| <b>Zone 1</b>    | Area in which an explosive gas–air mixture is likely to occur in normal operation                                                        |
| <b>Zone 2</b>    | Area in which an explosive gas–air mixture is not likely to occur in normal operation, and if it occurs will exist only for a short time |
| <b>Safe area</b> | By implication, an area that is not classified Zone 0, 1 or 2 is deemed to be a non-hazardous or safe area with respect to BS 5345       |

#### Examples of electrical area classification for various operations

| <i>Vapour source</i>                    | <i>Extent of classified area</i>                                                                                                                                                                                                                                                   | <i>Area classification</i>                                   |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| Vapour space inside storage tank        | Within the vapour space of the tank                                                                                                                                                                                                                                                | Zone 0                                                       |
| Storage tank outside buildings          | Vertically from ground level up to 2 m above the tank connections and horizontally within 2 m from the tank connections or shell                                                                                                                                                   | Zone 2                                                       |
| Discharge from vent line                | (a) Where liquids or vapours discharged from the vent may impinge<br>(b) Within 2 m in all other directions from point of discharge                                                                                                                                                | Fixed electrical equipment should not be installed<br>Zone 2 |
| Tank vehicle loading                    | (a) Vertically from ground level up to 2 m above, and horizontally outwards for 2 m from any point where connections are regularly made or disconnected for product transfer<br>(b) Vertically and horizontally between 2 m and 4 m from the points of connection or disconnection | Zone 1<br>Zone 2                                             |
| Pumps and sample points in the open air | Within 2 m in all directions                                                                                                                                                                                                                                                       | Zone 2                                                       |
| Pump house building                     | Within the building                                                                                                                                                                                                                                                                | Zone 1                                                       |

#### Notes

1. Where any area is classified under more than one factor, the higher classification should prevail.
2. Any banded area, pit, trench, depression or drain falling within a Zone 1 or Zone 2 area should be treated as being a Zone 1 area throughout.
3. Pump seals should be properly maintained.

or effects on site of fire, explosion, toxic release or similar incident. Selected sources of information are summarized in Table 12.7.

## Storage

### *Chemicals in packages*

The design of any building or outside compound for the storage of chemicals in packages (e.g. drums, cylinders, sacks) will depend upon their hazardous characteristics (pages 228, 248 and 272).

For a storage building the considerations include:

- Siting to minimize risk to nearby premises on and off site in a fire.
- Access for delivery and transfer of chemicals and for emergency purposes.
- Fire-proof construction.



**Table 12.7 Selected sources of spacing distances with hazardous chemicals (see Bibliography)**

|                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Preliminary minimum distances</b>                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                |
| Liquid oxygen                                                                                                            | <i>A Code of Practice for the Bulk Storage of Liquid Oxygen at Production Sites</i> (HSE, 1977)                                                                                                                                                                                                                                                                                |
| Liquefied flammable gases                                                                                                | <i>Process Plant Layout</i> page 562 (Mecklenburgh, 1985)                                                                                                                                                                                                                                                                                                                      |
| Liquids stored at ambient temperature and pressure                                                                       | <i>Process Plant Layout</i> page 564                                                                                                                                                                                                                                                                                                                                           |
| <b>Electrical area classification distances</b>                                                                          | <i>Process Plant Layout</i> pages 568–577                                                                                                                                                                                                                                                                                                                                      |
| <b>Distances for storage of explosives</b>                                                                               | <i>Explosive and Toxic Hazard Materials</i> page 370 (Meidl, 1970)<br><i>Safe Handling Requirements during Explosive, Propellant and Pyrotechnic Manufacture</i> (HSE, SIR 31)                                                                                                                                                                                                 |
| <b>General recommendations for spacing</b>                                                                               | <i>General Recommendations for Spacing in Refineries, Petrochemical Plants, Gasoline Plants, Terminals, Oil Pump Stations and Offshore Properties</i> (Oil Insurance Association, No. 361)                                                                                                                                                                                     |
| <b>‘Consultation’ distances</b> (in relation to major hazard and other sites, e.g. LPG, chlorine, for land use planning) | HSE assessments for consultation distances for major hazard installations, Chapter 5 in <i>Safety Cases</i> (Lees and Ang, 1989)                                                                                                                                                                                                                                               |
| <b>Minimum recommended spacing distances</b>                                                                             |                                                                                                                                                                                                                                                                                                                                                                                |
| Flammable liquids                                                                                                        | <i>Storage of Flammable Liquids in Tanks</i> (HSE, HSG 176)<br><i>Storage of Flammable Liquids in Containers</i> (HSE, HSG 51)<br><i>Storage of Highly Flammable Liquids</i> (HSE, CS2)<br><i>Highly Flammable Materials on Construction Sites</i> (HSE, HSG 3)<br><i>Storage of Flammable Liquids in Fixed Tanks, up to 10 000 m<sup>3</sup> Total Capacity</i> (HSE, HSG 50) |
| Liquefied petroleum gas                                                                                                  | <i>Storage of LPG at Fixed Installations</i> (HSE, HSG 34)<br><i>Storage and Use of LPG at Metered Estates</i> (HSE, CS11)<br><i>Storage and Use of LPG on Construction Sites</i> (HSE, CS6)<br><i>Keeping of LPG in Cylinders and Similar Containers</i> (HSE, CS4)                                                                                                           |
| <b>Distances for storage and handling of dangerous chemicals</b>                                                         | <i>Storage and Handling of Organic Peroxides</i> (HSE, CS21)<br><i>Chemical Warehousing Storage of Packaged Dangerous Substances</i> (HSE, HS(G) 71)<br><i>Safety Advice for Bulk Chlorine Installations</i> (HSE, HSG 28)<br><i>Storage and Handling of Industrial Nitrocellulose</i> (HSE, HSG 135)<br><i>Storage and Handling of Ammonium Nitrate</i> (HSE, CS18)           |

Security, i.e. control of access by staff and means to prevent entry by vandals or trespassers.  
General ventilation provisions, particularly if volatile toxic or highly flammable liquids, or toxic or flammable pressurized gases are stored.

Lighting, and emergency lighting, provisions.

Correct selection of heating equipment and zoning of electrical equipment to reduce the chance of an ignition source arising.

Provision of fire detection and extinguishment equipment.

The same factors arise for a dedicated compartment of a building. In either case identification and warning notices need to be provided.

Operation of the store (see Chapter 13) then needs to account for:

A system for checking that all packages entering the store have identifiable labels which indicate their contents and any hazardous characteristics.

A system for inspecting all packages received, and routinely in-store, for leaks, damage, external corrosion, etc.

A system for the segregation of chemicals, following the principles explained on page 136 and 248.

In-store handling of packages. Manual handling should be eliminated or reduced as far as possible. Fork-lift trucks should be regularly maintained, be provided with adequate access ways; driving should be restricted to fully-trained personnel.

Safe stacking practice. This will include provision of suitable racking, limitations on stack size and height, e.g. having regard to the potential severity of a fire.

Specification of a storage capacity and a procedure to avoid overfilling.

Good housekeeping.

Fire precautions including control of ignition sources, e.g. smoking, maintenance activities, vehicular access (see Chapter 6) and limitation of combustible materials, e.g. packaging.

## ***Drum storage***

Drums containing flammable liquids are preferably stored outside, so that any flammable vapour can readily disperse. Similar considerations may apply to the dispersion of any vapour/fumes from drums of toxic liquids or solids. In some cases weather protection is provided by a roof.

If outdoor storage is not reasonably practical a specially designed storeroom, preferably in a separate building, may be used.

A summary of recommendations for outdoor drum storage is given in Table 12.8.

**Table 12.8 Outdoor drum storage recommendations**

---

|                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| If possible, situate area remote from buildings and plant. Avoid location beneath pipe bridges or electric cable runs.                                                                                           |
| Secure the area to prevent tampering or trespassing.                                                                                                                                                             |
| Limit permissible fire load to $79 \times 10^5$ kJ or 250 tons of hydrocarbon.                                                                                                                                   |
| Label each drum; affix appropriate warning, e.g. 'Highly Flammable', 'Corrosive'.                                                                                                                                |
| Provide suitable absorbent materials to deal with spillages.                                                                                                                                                     |
| Limit stack heights, e.g. 4.5 m for 200 litres drums, 5 m high for drums stored on end or 4 m high on pallets, 4 m high for drums on their sides.                                                                |
| Segregate highly flammable liquids and mark the stack; classify the area as Zone 2. Place material >15 m from any working building, amenity building or plant and >7.5 m from plant boundary and boundary fence. |
| Space combustible material stacks >7.5 m from buildings and 4 m from plant boundary fences.                                                                                                                      |
| Limit areas for any stack of drums to 250 m <sup>2</sup> with generally a maximum length of 18.5 m. (A reduced area applies to particularly hazardous chemicals.)                                                |
| Restrict number of 180 litre drums to 1500.                                                                                                                                                                      |
| Ground should be impervious, and sloped and drained, with demarcation lines.                                                                                                                                     |
| Spillages from this area should be contained in a bund, or similar arrangement.                                                                                                                                  |
| Provide >5 m clearance between adjacent stacks with access on three sides for fire-fighting, etc.                                                                                                                |
| Provide an adequate number of fire hydrants for fixed monitors for drenching the stacks with water. Stack drums 2 m from any hydrants and leave clear access.                                                    |
| Leave space for possible hose runs for a fire in any stack and provide dry powder extinguishers around the area.                                                                                                 |

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## ***LPG in cylinders***

The risk with liquefied petroleum gas in cylinders is significantly greater than with a highly flammable liquid in drums because of the potential for rapid release of heavy flammable gas. In a fire around a cylinder there is a potential BLEVE hazard (see p. 178); ignition of a leak from a valve will cause a jet fire.

Therefore detailed recommendations relate to the keeping of liquefied petroleum gas in cylinders and similar containers. General recommendations for storage, other than on rooftops, are summarized in Tables 9.16–9.18.

## Equipment design

The design and instrumentation of individual equipment items are beyond the scope of this text. It is important to note, however, that:

All work equipment must be constructed or adapted to be suitable for its use, and its selection should have regard to the working conditions and risks to health and safety of persons where it is used and any additional risks it poses (Provision and Use of Work Equipment 1998 Reg. 2).

In addition to guarding dangerous machinery (Reg. 11) measures are required to prevent or adequately control hazards from work equipment due to:

- any article or substance falling or being ejected;
- rupture or disintegration of parts;
- it catching fire or overheating;
- the unintended discharge or premature discharge of any gas, dust, liquid, vapour or other substance; consideration should also be given to fugitive emissions or leaks from valves, flanges, connections, seals, pumps, agitators, etc. by, for example, using average emission factors for common plant equipment such as those given in Table 12.9. (Such assessments may be important in reducing material loss or in estimating potential employee exposure or environmental pollution levels);
- the unintended or premature explosion of it or any substance in it (Reg. 12).

The selection of materials of construction is subject to the considerations of corrosion summarized on page 54.

Consideration should be given to the safety features listed in Table 7.21.

For any pressure system there are obligatory requirements summarized on page 423.

**Table 12.9 Average emission factors for plant items**

| <i>Equipment</i>       | <i>Service</i> | <i>Emission factors (kg/hr)*</i> |                                                 |
|------------------------|----------------|----------------------------------|-------------------------------------------------|
|                        |                | <i>Refineries</i>                | <i>Synthetic organic chemical manufacturing</i> |
| Valves                 | Gas            | 0.27                             | 0.0056                                          |
|                        | Light liquid   | 0.11                             | 0.0071                                          |
|                        | Heavy liquid   | 0.00022                          | 0.00023                                         |
| Pump seals             | Light liquid   | 0.11                             | 0.0494                                          |
|                        | Heavy liquid   | 0.021                            | 0.0214                                          |
| Compressors            | Gas/vapour     | 0.64                             | 0.228                                           |
| Pressure relief valves | Gas/vapour     | 0.16                             | 0.104                                           |
| Flanges                | All            | 0.00025                          | 0.00083                                         |
| Open-ended lines       | All            | 0.0023                           | 0.0017                                          |
| Sampling connections   | All            | 0.015                            | 0.015                                           |

\*Multiplying the total number of items in a unit by the factor provides an indication of the emission rate.

## Piping arrangements

Complex piping systems may be required for the transfer of chemicals, balancing of pressures, venting, drainage, supply of services, etc.

Safe operation is generally assisted by simplification of piping and valve arrangements, and by their identification, e.g. by colour coding or tags. Logical arrangement can also serve as a prompt in identification.

Design of piping systems is a special discipline but some guidance is given in Table 12.10.

**Table 12.10 Design measures to reduce leaks from pipework**

---

|                                                                                                                                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Minimize the number of branches and deadlegs.                                                                                                      |
| Minimize the number of small drain lines.                                                                                                          |
| Design small diameter lines to the same codes, and test to the same standards, as main lines; reinforce junctions as necessary.                    |
| Provide flexibility to allow for thermal expansion, or contraction, of pipework and connected equipment.                                           |
| Direct discharges from automatic drains to visible locations.                                                                                      |
| Provide gaskets compatible with the internal fluid over the full range of temperatures and pressures.                                              |
| Provide removable plugs on valve sample points.                                                                                                    |
| Provide adequate pipe supports.                                                                                                                    |
| Minimize the number of flanges on vacuum lines.                                                                                                    |
| Consider duplication, locking, temporary blanking of valves on 'open' discharge lines.                                                             |
| Either avoid pipe runs along routes subject to possible mechanical damage, e.g. from fork-lift trucks or tankers, or provide shields and barriers. |
| Provide walkways, ladders, etc. to avoid pipework being clambered over.                                                                            |
| Minimize the use of flexible hoses; if used:                                                                                                       |
| – ensure hose and couplings are to the appropriate standard;                                                                                       |
| – provide for rapid isolation in any emergency;                                                                                                    |
| – use bolted, not jubilee, clips;                                                                                                                  |
| – consider self-sealing couplings;                                                                                                                 |
| – provide adequate support and protection whilst in use;                                                                                           |
| – protect from crushing or contamination when not in use.                                                                                          |

---

## ***Services and utilities***

Ensure the adequacy (in terms of quality, quantity and reliability) of services/utilities, e.g. steam, process/cooling water, electricity, compressed air, inert gas, fire suppression systems, ventilation. Stand-by or emergency services may be required. Some general safety design considerations are summarized in Table 12.11.

Ventilation can be provided as general dilution ventilation or local extraction ventilation.

### ***Dilution ventilation (general ventilation)***

Open construction is preferable wherever practicable for areas processing hazardous chemicals, to provide general ventilation and assist in the dispersion of leaking gas or vapour, to maximize explosion-venting area and to facilitate fire-fighting. Local dilution ventilation is provided to flush the workplace atmosphere with clean air and thus dilute the level of contaminant in ambient air to acceptable levels. The siting of the extract fans and the air inlets require careful consideration to minimize operator exposure (Figure 12.1). The general rules are:

- Site the exhaust fan near to the source of contaminant.
- Ensure that fresh air movement is from worker to leak source and not vice versa.
- Ensure that air inlet supply is not contaminated with exhaust effluent.
- Provide back-up for air inlet where necessary.

**Table 12.11 Safety considerations for plant services design**


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|                                                                                                                                                                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The need to duplicate power supplies to equipment.                                                                                                                                           |
| The need to duplicate or triplicate equipment.                                                                                                                                               |
| Selection between steam, or electricity, or a combination for pumps and compressors.                                                                                                         |
| Provision of automatic start for spare pumps.                                                                                                                                                |
| Provision of voltage protection for key equipment which must be kept on-line or be restarted quickly.                                                                                        |
| Order for restarting equipment after a power failure.                                                                                                                                        |
| Extent of emergency power supplies for lighting, communication systems, and key items of equipment (e.g. cooling facilities, reactor agitators, exhaust ventilation) and instruments/alarms. |
| Provision for cooling emergency equipment, e.g. diesel generators if cooling water is disrupted.                                                                                             |
| Required positioning of control valves (i.e. shut, open or 'as is') upon power failure.                                                                                                      |
| Provision of compressed air, inert gas from reservoirs for a limited period.                                                                                                                 |
| Provision for alternative fire water supply.                                                                                                                                                 |
| Provision of efficient drift eliminators of water cooling towers; consideration of replacement by air cooling systems.                                                                       |
| Thermal insulation to protect personnel from contact with hot or cold surfaces; prevention of water supply disruption by freezing.                                                           |
| Design of hot and cold water services to avoid water standing undisturbed for long periods. Use of covered tanks and cisterns with approved fittings and materials.                          |
| Avoidance of cold water temperatures of 20 C–45 C, storage of hot water at 60 C and circulation at 50 C.                                                                                     |

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For continuous release of gas or vapour the steady-state dilution ventilation required to reduce the atmospheric pollutant to a level below its hygiene standard is given by

$$Q = \frac{3.34 \times 10 \times SG \times ER \times K}{MW \times HS}$$

where  $Q$  is the ventilation rate (m/min)

$SG$  is the specific gravity of the evaporating liquid

$ER$  is the rate of evaporation (l/hr)

$MW$  is the molecular weight

$K$  is the design factor

$HS$  is the hygiene standard.

In general, dilution ventilation alone is inappropriate for highly-toxic substances, carcinogens, dusts or fumes or for widely fluctuating levels of pollutants. Since hygiene standards are often revised (usually downwards), specifications of existing systems may prove inadequate. An inherent problem is that contaminants may have to pass through a worker's breathing zone before dilution.

### *Local exhaust ventilation*

Local exhaust ventilation serves to remove a contaminant near its source of emission into the atmosphere of a workplace. A system normally comprises a hood, ducting which conveys exhausted air and contaminants, a fan, equipment for contaminants collection/removal and a stack for dispersion of decontaminated air. Hoods normally comprise an enclosure, a booth, a captor hood or a receptor hood. Those relying on other than complete enclosure should be as close as practicable to the source of pollution to achieve maximum efficiency.

*Total enclosure* may be in the form of a room with grilles to facilitate air flow; this functions as a hood and operates under a slight negative pressure with controls located externally. Entry is restricted and usually entails use of comprehensive personal protective equipment. Ancillary requirements may include air filters/scrubbers, atmospheric monitoring, decontamination procedures and a permit-to-work system (see page 417).

*Partial enclosure* allows small openings for charging/removal of apparatus and chemicals. The requisite air velocity to prevent dust or fumes leaking out determines the air extraction rate, e.g.

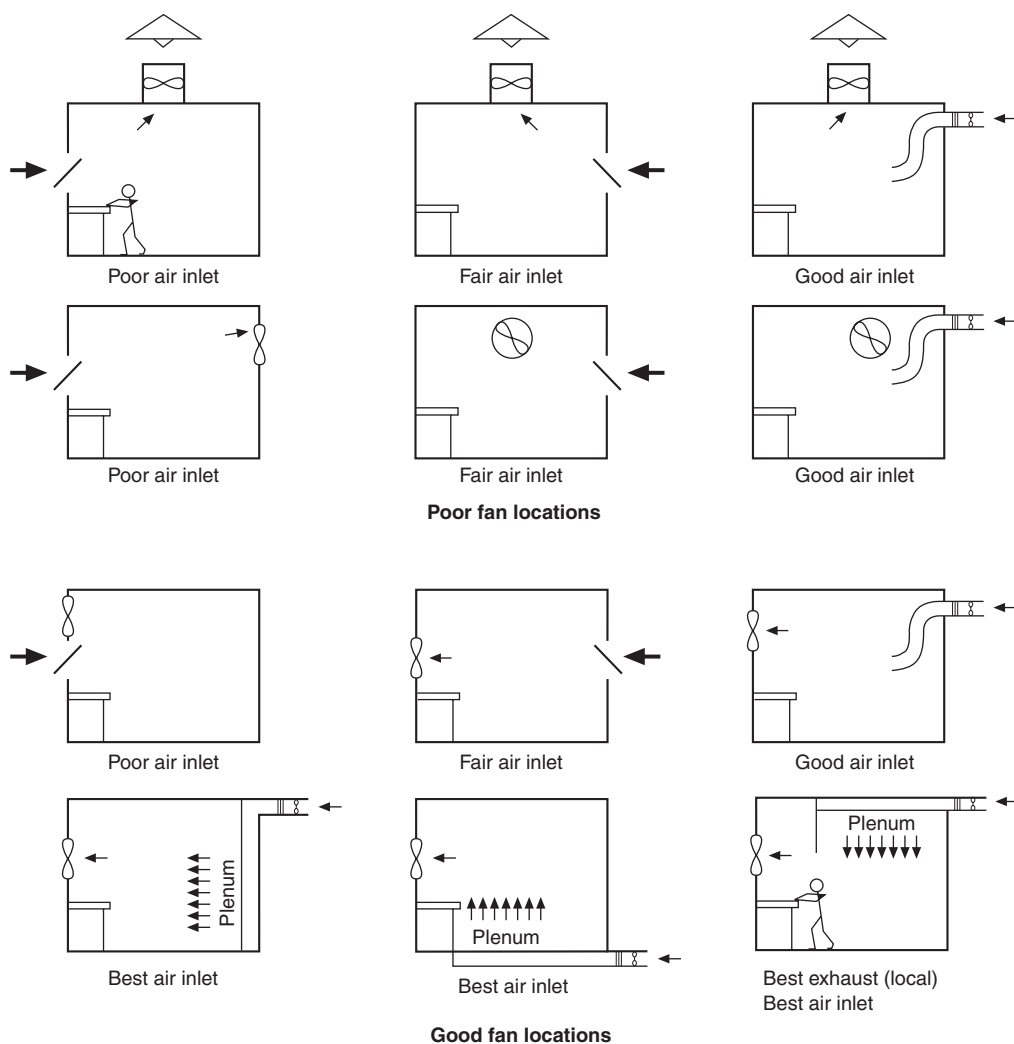


**Figure 12.1** Dilution ventilation: inlet air may require tempering according to outside conditions

in the range 0.28 to 0.56 m/s. A higher velocity is required if there is significant dispersion inside the enclosure.

A *booth* should be of sufficient size to contain any naturally occurring emissions and so minimize escape via the open face. An air velocity of 0.56 m/s is required over the whole open face; a higher velocity is needed if there is significant air movement within the booth or to cope with convection currents. Booths should be deep enough to contain eddies at the rear corners; baffle plates or multiple offtakes may be necessary with shallow booths.

No operator should work between the source of pollutant and the rear of the booth (i.e. all work should be handled from the front open face, as illustrated by Figure 12.1).

If enclosure or use of a booth is impracticable, a *captor hood* is used. This is placed some distance from the source of pollution and the rate of air flow needs to be such as to capture contaminants at the furthestmost point of origin.

Typical capture velocities are given in Table 12.12. Since velocity falls off rapidly with distance from the face of the hood, as shown in Figure 12.2, any source of dust should be within one hood

**Table 12.12** Range of capture velocities

| Condition of dispersion of contaminant               | Examples                                                                                                         | Capture velocity (m/s)         |
|------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------|
| Released with practically no velocity into quiet air | Evaporation from tanks<br>Degreasing vats etc.                                                                   | 0.25–0.51                      |
| Released at low velocity into moderately still air   | Spray booths<br>Intermittent container filling<br>Low-speed conveyor transfers<br>Welding<br>Plating<br>Pickling | 0.51–1.02                      |
| Active generation into zone of rapid air motion      | Spray painting in shallow booths<br>Barrel filling<br>Conveyor loading<br>Crushers                               | 1.02–2.54                      |
| Released at high initial velocity into zone of very  | Grinding<br>rapid air motion<br>Tumbling                                                                         | 2.54–10.2<br>Abrasive blasting |

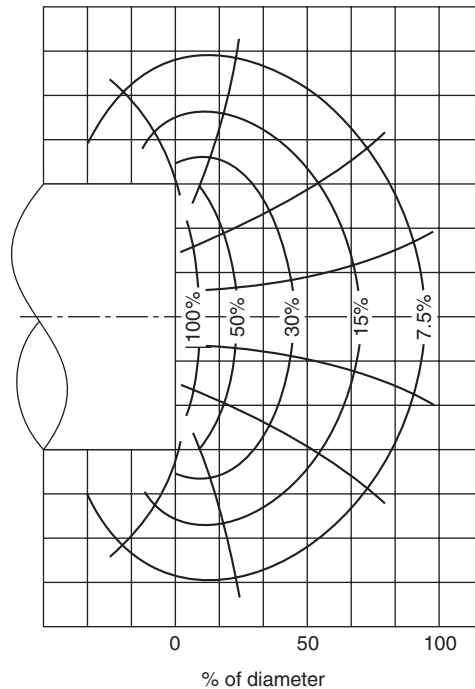


**Figure 12.2** Reduction in air velocity with distance from captor hood (distance given as % of hood diameter)

diameter. Efficiency can be significantly improved by the use of flanges and by avoiding abrupt changes in direction of the ducting.

A *receptor hood* receives a contaminant driven into it by the source of generation. The flowrate needs to ensure that the hood is emptied more rapidly than the process fills it and to overcome draughts. No operator should work between the hood and the source of the contaminants.

Whatever the type of ventilation, air flow must be adequate to prevent particulate matter settling in the ducting; typical transport velocities are given in Table 12.13.

**Table 12.13 Typical recommended transport velocities**

| <i>Material, operation or industry</i> | <i>Minimum transport velocity</i> |           |
|----------------------------------------|-----------------------------------|-----------|
|                                        | (m/s)                             | (ft/min)  |
| Abrasive blasting                      | 17.8–20.3                         | 3500–4000 |
| Aluminium dust, coarse                 | 20.3                              | 4000      |
| Asbestos carding                       | 15.2                              | 3000      |
| Bakelite moulding powder dust          | 12.7                              | 2500      |
| Barrel filling or dumping              | 17.8–20.3                         | 3500–4000 |
| Belt conveyors                         | 17.8                              | 3500      |
| Bins and hoppers                       | 17.8                              | 3500      |
| Brass turnings                         | 20.3                              | 4000      |
| Bucket elevators                       | 17.8                              | 3500      |
| Buffing and polishing                  |                                   |           |
| dry                                    | 15.2–17.8                         | 3000–3500 |
| sticky                                 | 17.8–22.9                         | 3500–4500 |
| Cast iron boring dust                  | 20.3                              | 4000      |
| Ceramics                               |                                   |           |
| glaze spraying                         | 12.7                              | 2500      |
| brushing                               | 17.8                              | 3500      |
| fettling                               | 17.8                              | 3500      |
| dry pan mixing                         | 17.8                              | 3500      |
| dry press                              | 17.8                              | 3500      |
| sagger filling                         | 17.8                              | 3500      |
| Clay dust                              | 17.8                              | 3500      |
| Coal (powdered) dust                   | 20.3                              | 4000      |
| Cocoa dust                             | 15.2                              | 3000      |
| Cork (ground) dust                     | 12.7                              | 2500      |
| Cotton dust                            | 15.2                              | 3000      |
| Crushers                               | 15.2                              | 3000      |
| Flour dust                             | 12.7                              | 2500      |
| Foundry, general                       | 17.8                              | 3500      |
| sand mixer                             | 17.8–20.3                         | 3500–4000 |
| shakeout                               | 17.8–20.3                         | 3500–4000 |
| swing grinding booth exhaust           | 15.2                              | 3000      |
| tumbling mills                         | 20.3–25.4                         | 4000–5000 |
| Grain dust                             | 12.7–15.2                         | 2500–3000 |
| Grinding, general                      | 17.8–22.9                         | 3500–4500 |
| portable hand grinding                 | 17.8                              | 3500      |
| Jute                                   |                                   |           |
| dust                                   | 12.7–15.2                         | 2500–3000 |
| lint                                   | 15.2                              | 3000      |
| dust shaker waste                      | 16.3                              | 3200      |
| pickerstock                            | 15.2                              | 3000      |
| Lead dust                              | 20.3                              | 4000      |
| with small chips                       | 25.4                              | 5000      |
| Leather dust                           | 17.8                              | 3500      |
| Limestone dust                         | 17.8                              | 3500      |
| Lint                                   | 10.2                              | 2000      |
| Magnesium dust, coarse                 | 20.3                              | 4000      |
| Metal turnings                         | 20.3–25.4                         | 4000–5000 |
| Packaging, weighing etc.               | 15.2                              | 3000      |
| downdraft grille                       | 17.8                              | 3500      |
| Pharmaceutical coating pans            | 15.2                              | 3000      |
| Plastics dust (buffing)                | 19.0                              | 3800      |
| Plating                                | 10.2                              | 2000      |



**Table 12.13** Cont'd

| <i>Material, operation or industry</i>     | <i>Minimum transport velocity</i> |           |
|--------------------------------------------|-----------------------------------|-----------|
|                                            | (m/s)                             | (ft/min)  |
| Rubber dust                                |                                   |           |
| fine                                       | 12.7                              | 2500      |
| coarse                                     | 20.3                              | 4000      |
| Screens                                    |                                   |           |
| cylindrical                                | 17.8                              | 3500      |
| flat deck                                  | 17.8                              | 3500      |
| Silica dust                                | 17.8–22.9                         | 3500–4500 |
| Soap dust                                  | 15.2                              | 3000      |
| Soapstone dust                             | 17.8                              | 3500      |
| Soldering and tinning                      | 12.7                              | 2500      |
| Spray painting                             | 10.2                              | 2000      |
| Starch dust                                | 15.2                              | 3000      |
| Stone cutting and finishing                | 17.8                              | 3500      |
| Tobacco dust                               | 17.8                              | 3500      |
| Woodworking                                |                                   |           |
| wood flour, light dry sawdust and shavings | 12.7                              | 2500      |
| heavy shavings, damp sawdust               | 17.8                              | 3500      |
| heavy wood chips, waste, green shavings    | 20.3                              | 4000      |
| hog waste                                  | 15.2                              | 3000      |
| Wool                                       | 15.2                              | 3000      |
| Zinc oxide fume                            | 10.2                              | 2000      |

## Fire protection

The installation of fixed fire protection depends on analysis of potential fire characteristics (see Chapter 6). A summary of the factors is given in Table 12.14.

**Table 12.14** Fire characteristics determining protection system design

|                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Types of combustibles, e.g. resulting in surface fires for which inerting or an inhibiting agent may be best, or deep-seated combustion requiring a cooling agent, e.g. water.                 |
| Relative importance of speed of detection.                                                                                                                                                     |
| Degree of risk to personnel, e.g. toxic combustion or fire-fighting agent decomposition products.                                                                                              |
| Indoors, indicative of a total flooding system; outdoors requiring assessment of exposure of nearby hazards, involvement of other combustibles, wind effects and difficulty of extinguishment. |
| Probability of fire spread, with a need for, e.g., fire walls, fire doors, fire stops.                                                                                                         |
| Requirement for detection and control, or detection and extinguishment.                                                                                                                        |
| Any features which rule out specific extinguishing agents, or making other types preferable.                                                                                                   |
| Any advantages of a dual agent system, e.g. water and carbon dioxide.                                                                                                                          |
| Inherent or possible explosion risks (e.g. static discharge associated with extinguishant discharge).                                                                                          |
| Need for operation with personnel present.                                                                                                                                                     |
| Need for rapid 'knock-down'.                                                                                                                                                                   |

Activation may be automatic, by a detection system, or manual. The general requirements are summarized in Table 12.15.

**Table 12.15 General requirements for fixed fire extinguishing system**

---

|                                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Capability to control and extinguish the anticipated fire condition without outside assistance, unless planned for (dependent on requisite spacing of discharge nozzles to cover all areas at risk, application rates, discharge times, quantities of extinguishant available). |
| Reliability, allowing for environmental features possibly detrimental to operation, e.g. corrosion, dust, tar.                                                                                                                                                                  |
| Agents must be compatible with the process, chemicals present (Chapter 7) and any other installed system.                                                                                                                                                                       |
| Potential toxicity of the agent, its thermal breakdown products, or products generated on contact with chemicals will determine safety measures necessary (e.g. in occupied areas a 'double-knock' system, allowing evacuation time, may be required).                          |
| Visibility in the fire zone after extinguishant discharge, if manual fire-fighting is anticipated.                                                                                                                                                                              |

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**Installation and operation**

Engineering specification and purchasing procedures are essential to ensure that all items are to the design specification and to comply with company or national standards. During installation the features to consider are foundations, selection of materials, fabrication, assembly, supports, pressure testing, etc.

# Operating procedures

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Safety is a management responsibility requiring an awareness of all relevant local legislation and a strategy that comprises:

- A clear, widely-published statement of company policy on safety.
- Clear lines of responsibility identified for each level of management and the workforce to enable the policy to be implemented.
- Company management systems and 'safe systems of work'.
- Emergency procedures.
- Procedures for monitoring compliance with the policy and the safety performance.

In the UK these duties are imposed by the Health and Safety at Work etc. Act. Employees also have a legal responsibility to cooperate with management by using designated protective devices and not interfering with such apparatus.

An excellent framework for the management of occupational health and safety is provided by OHSAS 18001:1999 which is compatible with ISO 9001: 1994. Key elements of the standard addressed include

- Policy.
- Legislation.
- Hazard identification and risk assessment and risk control.
- Structure and responsibilities.
- Training, awareness and competence.
- Consultation and communication.
- Documentation.
- Documentation and data control.
- Operational control.
- Emergency preparedness and response.
- Performance measurement and monitoring.
- Accidents, incidents, non-conformances and corrective and preventative action.
- Records and their management
- Audits.
- Management review and continuous improvement.

Plant must be properly designed, installed, commissioned, operated and maintained. Depending upon the risk, working procedures should be documented, e.g. as codes of practice. Consideration of safety at the design stage was discussed in Chapter 12.

## Commissioning

Commissioning embraces those activities essential for bringing a newly installed plant into routine production. It includes mechanical completion and provisional acceptance, pre-commissioning, first start-up and post-commissioning.

Special efforts are needed to ensure safety at this stage of the development. Since start-up and shutdown procedures are responsible for many accidents, these procedures merit special attention.

## Operation

Operation includes normal start-up, normal and emergency shutdown, and most activities performed by the production team. Whilst inherently safe plant design limits inventories of hazardous substances, inherently safe operation ensures the number of individuals at risk are minimized. Access to the plant for non-essential operational people such as maintenance engineers, post staff, administrators, quality control samplers, warehouse staff delivering raw material or plant items or collecting finished product, members of security, visitors etc., must be controlled.

Safe handling of chemicals demands a combination of 'hardware' and 'software' such as operating procedures, staff selection and training. Within the UK there is a duty under the Management of Health and Safety at Work Regulations 1992 for an employer to make appropriate arrangements for the effective planning, organization, control, monitoring and review of the preventive and protective measures. Systems of work will generally include:

- The selection and supervision of personnel with clearly-defined job descriptions.

- Planning and coordination of all activities – in particular those involving different sections, departments or tradesmen.

- Training and instruction of the workforce. Retraining. This should cover both normal and emergency situations.

- Provision of operating instructions and procedures. These should eliminate confusion and provide continuity on, e.g., shift changeover. Errors in identification of valves, pumps, pipes, storage tanks, and the sequence in which they are to be operated is a common cause of accidents, e.g. on staff changeovers.

- Provision of adequate supervision.

- Inspection, testing, maintenance and replacement of equipment as necessary.

- General conditions of work, e.g. maintenance of adequate general ventilation, local exhaust ventilation, access, lighting, fire precautions, occupational health measures, housekeeping.

- Auditing of health, safety and environmental matters.

A checklist is given in Table 13.1.

## Maintenance

Maintenance embraces regular inspection, periodic examination by 'competent persons', and repairs. Accidents may arise as a result of the lack of maintenance, during maintenance, and as a consequence of faulty maintenance. Preventive maintenance can be a legal requirement for, e.g., pressure vessels/boilers, lifting gear, power presses. A system is required for monitoring compliance with scheduled preventive maintenance programmes, backed up by in-service inspection. Breakdown

Table 13.1 Safety systems in operation

|                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|---------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Access</b>                                                                         | <p><i>System for</i></p> <p>Control of access to site; maintenance of security</p> <p>Designation of restricted areas, e.g. containing flammable materials, 'eye protection' zones, 'hearing protection' zones, radiological hazards, microbiological hazards</p> <p>Ensuring freedom from obstruction of roads, stairs, gangways, escape routes</p> <p>Control of vehicles</p>                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Communication systems</b>                                                          | <p><i>Maintenance of adequate</i></p> <p>Written instructions, maintenance procedures etc.</p> <p>Log books, recipe sheets, batch sheets</p> <p>Identification of vessels, lines, valves etc.</p> <p>Intershift communication and records</p> <p>System for reporting and follow-up of</p> <ul style="list-style-type: none"> <li>Plant defects</li> <li>Process deviations</li> <li>Hazardous occurrences ('near misses')</li> <li>Accidents: minor/major injury and/or material loss</li> </ul> <p>Warnings, notices</p> <ul style="list-style-type: none"> <li>Notices relating to specific hazards</li> <li>Notices relating to temporary hazards (and their subsequent removal)</li> </ul> <p>(See also permit-to-work systems and operating procedures)</p> <p>Alarms; emergency communications</p> |
| <b>Control of contractors</b>                                                         | <p>Familiarization with plant hazards, rules and safety practices, security</p> <p>Clear delineation of work, responsibilities and handover</p> <p>(See also maintenance, permit-to-work systems, personal protection, site restrictions, access, modifications, personal hygiene etc.)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <b>First aid provisions</b>                                                           | <p><i>Maintenance of adequate provision for</i></p> <p>Emergency showering</p> <p>Eye-washing</p> <p>Decontamination from chemicals (and antidotes if relevant)</p> <p>First aid (equipment, materials, trained personnel) and resuscitation</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Housekeeping</b>                                                                   | <p>Regular cleaning of floors, ledges, windows, by appropriate procedures (e.g. 'dustfree' methods)</p> <p>Removal of empty containers, scrap, waste</p> <p>Prompt treatment of spillages</p> <p>Redecoration</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Inspection and testing</b><br>(including cleaning/<br>maintenance where necessary) | <p><i>Implementation of a system for routine, regular inspection of</i></p> <p>General ventilation provisions</p> <p>Local exhaust ventilation provisions (test and report at regular intervals)</p> <p>Fire protection</p> <p>Alarm systems (HTA, HPA, fire, evacuation etc.)</p> <p>Plant and equipment generally; portable tools; flexible hoses; lifting equipment; pressure systems</p> <p>Safety devices, e.g. PSVs, explosion reliefs, trips</p> <p>Monitoring and control instruments</p> <p>Protective clothing/equipment and emergency equipment</p> <p>Drains and floor drainage; bund walls</p> <p>Electrical equipment; earthing and bonding</p>                                                                                                                                             |
| <b>Maintenance</b>                                                                    | <p><i>Systems include arrangements for</i></p> <p>Issue, control, testing and repair of lifting gear, ladders, scaffolding etc.</p> <p>Scheduled maintenance of key plant items</p> <p>Use of job cards/log book to identify tasks precisely</p> <p>Permit-to-work systems</p> <ul style="list-style-type: none"> <li>Flame cutting/welding (or soldering, brazing etc.)</li> <li>Line-breaking</li> <li>Electrical work – certain classifications</li> <li>Equipment removal, e.g. to workshop</li> <li>Work on roof/at heights</li> </ul>                                                                                                                                                                                                                                                               |

Table 13.1 Cont'd

|                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                          | <ul style="list-style-type: none"> <li>Isolation of safety services</li> <li>Excavations</li> <li>Introduction of non-flameproof electrical equipment into restricted area</li> <li>Mechanical isolation, e.g. conveyors, lifts</li> <li>Confined space entry</li> <li>Radioactive areas</li> <li>Microbiological ventilation systems, fume cupboards etc.</li> <li>Other unusual/non-routine situations</li> <li>Provision for trained persons to be present/on call, e.g. rescue, first aid, fire-fighting</li> <li>Instruction and training of personnel</li> <li>Maintenance of guards on machinery, open vessels, handrails, screens at sampling/drumming-up points etc. and on glass equipment</li> <li>Use of sparkproof tools where appropriate</li> <li>Record-keeping</li> <li>Inspections, e.g. pressure systems, trips, relief devices, guards, lighting (see inspection and testing)</li> </ul> |
| <b>Materials</b>                         | <ul style="list-style-type: none"> <li><i>Maintenance of adequate procedures for</i></li> <li>In bulk, e.g. checks on tanker contents, earthing and bonding, identification of receiving vessel</li> <li>In small containers, e.g. carboy handling, cylinder unloading</li> <li>Despatch of materials <ul style="list-style-type: none"> <li>Inspection of tankers, carboys, cylinders etc. prior to filling</li> <li>Identification and labelling of materials; driver instructions</li> </ul> </li> <li>Use of earthing clips on portable containers of flammable liquids</li> </ul>                                                                                                                                                                                                                                                                                                                       |
| <b>Modifications to plant or process</b> | <ul style="list-style-type: none"> <li><i>System for</i></li> <li>Control of changes in raw materials</li> <li>Formal approval for plant/process changes</li> <li>Hazard and operability study prior to implementation (repeat when in use)</li> <li>Updating of all operating instructions, notices, procedures</li> <li>Removal/isolation of obsolete plant/lines</li> <li>Control of changes in personnel (see training)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Monitoring and follow-up</b>          | <ul style="list-style-type: none"> <li><i>Systems for monitoring</i></li> <li>Working environments <ul style="list-style-type: none"> <li>Toxic contaminants</li> <li>Temperature</li> <li>Noise</li> <li>Lighting</li> <li>Vibration</li> <li>Ionizing radiation</li> </ul> </li> <li>Occupational health <ul style="list-style-type: none"> <li>Pre-employment medical for selection and establishment of base levels</li> <li>Working conditions in specific areas</li> <li>Employees' routine medicals, exposure profiles</li> <li>Biological monitoring where appropriate</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                        |
| <b>Operating procedures</b>              | <ul style="list-style-type: none"> <li><i>Systems include</i></li> <li>Provision of clearly written operating instructions, accessible to operators, referring to numbered/identified plant items, covering <ul style="list-style-type: none"> <li>Start-up and shutdown</li> <li>Normal operation, draining, purging, excursions etc.</li> <li>Operation at high or low rates</li> <li>Emergency shutdown, service failures etc.</li> <li>Procedures for non-routine operations, e.g. clearance of blockages, reprocessing of materials, temporary process alteration</li> <li>Pressure testing, sampling, chemical and atmospheric testing</li> </ul> </li> <li>Established procedures for draining, purging, venting, isolating, testing and inspection prior to opening/entering/maintaining plant (see permit-to-work systems, maintenance)</li> </ul>                                                  |

Table 13.1 Cont'd

|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      | <p>Quality control on raw materials, materials in process, products and wastes</p> <p>Materials control to enable losses, over-use, under-use or accumulations to be detected; control of quantities in storage</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Permit-to-work systems</b>        | <p>See under 'Maintenance'</p> <p>Entry into confined spaces (e.g. vat, vessel, flue, sewer, boiler or similar)</p> <p>Use of non-flameproof electrical equipment where flammable liquids/vapours/dusts may arise</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Personal hygiene</b>              | <p><i>Checks on</i></p> <p>Adequacy of washing/showering facilities (location and provision)</p> <p>Skin cleansing, barrier and conditioning cream provision</p> <p>Double locker system</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Personal protection</b>           | <p><i>Systems to ensure provision of</i></p> <p>Overalls: special requirements (flame retardant, antistatic), frequency of laundering</p> <p>Protective clothing: suits, spats, armlets, helmets, gloves for specific applications, footwear (industrial and/or antistatic)</p> <p>Hearing protectors</p> <p>Eye protection: specific provision for various duties</p> <p>Respirators: specific types for different applications</p>                                                                                                                                                                                                                                                                                  |
| <b>Safety management</b>             | <p><i>Systems include</i></p> <p>Safety audit system: hazard analysis</p> <p>Checks on the adequacy and location of fire-fighting, emergency rescue and alarm equipment</p> <p>Practice in emergency situations</p> <p>Emergency procedures for</p> <ul style="list-style-type: none"> <li>Fire/explosion</li> <li>Toxic release</li> <li>Serious accidents</li> <li>Spillage</li> <li>Pollution incidents</li> </ul> <p>(particularly when manning levels are low, e.g. weekends)</p> <p>Major emergency procedures</p> <ul style="list-style-type: none"> <li>Internal procedures (evacuation, communications, shutdown, damage control)</li> <li>External liaison (fire, police, hospitals, neighbours)</li> </ul> |
| <b>Site restrictions</b>             | <p><i>Systems include</i></p> <p>Control over chemicals, containers etc. removal from site (<i>see also</i> waste disposal)</p> <p>Prohibition of eating/drinking except in designated areas</p> <p>Prohibition of smoking, carrying matches/lighters, except in designated areas; arrangements for enforcing this</p> <p>Restriction on employees permitted to drive works transport</p> <p>Control of lone working</p> <p>Control over equipment removal from site</p>                                                                                                                                                                                                                                              |
| <b>Storage</b>                       | <p><i>Procedures for ensuring</i></p> <p>Identification of all materials</p> <p>Segregation of incompatible materials</p> <p>Good housekeeping</p> <p>Compliance with limits set for stocks of potentially hazardous chemicals</p> <p>Storage, segregation and handling of gas cylinders</p> <p>Display of appropriate warnings/notices</p>                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Training: management</b>          | <p><i>Provision for</i></p> <p>Refresher course on fundamentals of safety, hazard recognition, procedures</p> <p>Participation in hazard and operability studies on existing operations and procedures</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Training: operating personnel</b> | <p><i>Provision for</i></p> <p>Formal training programme; refresher courses</p> <p>Instruction in hazards associated with the work and safe procedures</p> <p>Introduction of new legislation</p> <p>Instruction and practice in emergency procedures</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

Table 13.1 Cont'd

|                       |                                                                                                                             |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------|
| <b>Waste disposal</b> | Encouragement/enforcement of use of personal protection                                                                     |
|                       | Special training needs, e.g. first aid, emergency rescue/fire-fighting                                                      |
|                       | <i>Systems for</i>                                                                                                          |
|                       | Collection of combustible waste in appropriate containers (e.g. oily rags/other material subject to spontaneous combustion) |
|                       | Identification of wastes; analytical control procedures; labelling of containers                                            |
|                       | Segregation of wastes; identification of hazards due to inadvertent mixing of wastes                                        |
|                       | Selection of appropriate disposal routes for liquids/solids to comply with acceptable discharge levels                      |
|                       | Disposal of toxic waste                                                                                                     |

maintenance is also required to correct faults and repair damage. All maintenance on equipment used with chemicals should be properly planned following a risk assessment, and recorded. Maintenance operations, particularly those which are non-routine, require a sound system of work with strict administrative procedures, e.g. permit-to-work, to avoid risks arising from modifications to established safe practices. A permit-to-work should be used wherever the method by which a job is done is likely to be critical to the safety of the workers involved, nearby workers, or the public; it is required whenever the safeguards provided in normal operations are no longer available. The system has written instructions to explain how it operates and to which jobs it is applicable. A form is used to control the work. This must be issued by a responsible person and the recipient must be trained in the system and how to perform the work. Different forms are applied to different tasks. Examples include:

Entry into confined spaces where there is likely to be a danger from toxic or flammable gases, ingress or presence of liquids, free-flowing solids, or oxygen deficiency or enrichment, etc. (Table 13.2). Such work requires well-rehearsed procedures regulated by a permit. Figure 13.1 identifies the procedures for entry into confined spaces and Table 13.3 lists associated safety requirements with a specimen permit (Figure 13.2). Detailed requirements in the UK are specified in the Confined Spaces Regulations 1997.

Hot work on plant, or in areas where flammable materials are handled, e.g. arc or gas welding (see also Figure 5.4), flame-cutting, use of blow torches, grinding chipping concrete, introduction of non-sparkproof vehicles.

Table 13.2 Control of oxygen gas

Ease of ignition, combustion rate and combustion temperature all increase when the oxygen content of an atmosphere >21% (Chapter 6).

Enrichment of a room atmosphere >25% creates a hazardous situation: enrichment in a confined space is particularly dangerous.

#### Precautions include

Never use oxygen to 'sweeten' the atmosphere in a confined space

When flame-cutting metals:

Use proper ventilation (all the oxygen supply to the torch may not be consumed)

Do not nip/kink the hose to cut off the oxygen supply while changing torches – always use the isolation valve

Do not leave blowpipes or torches inside a confined space during breaks

Wherever possible locate the cylinder outside the confined space

Do not use oxygen gas as a source of pressure in place of compressed air

Keep regulators, valves and piping on compressed gas systems clean and free from oil and grease

Close the cylinder valve when not in use



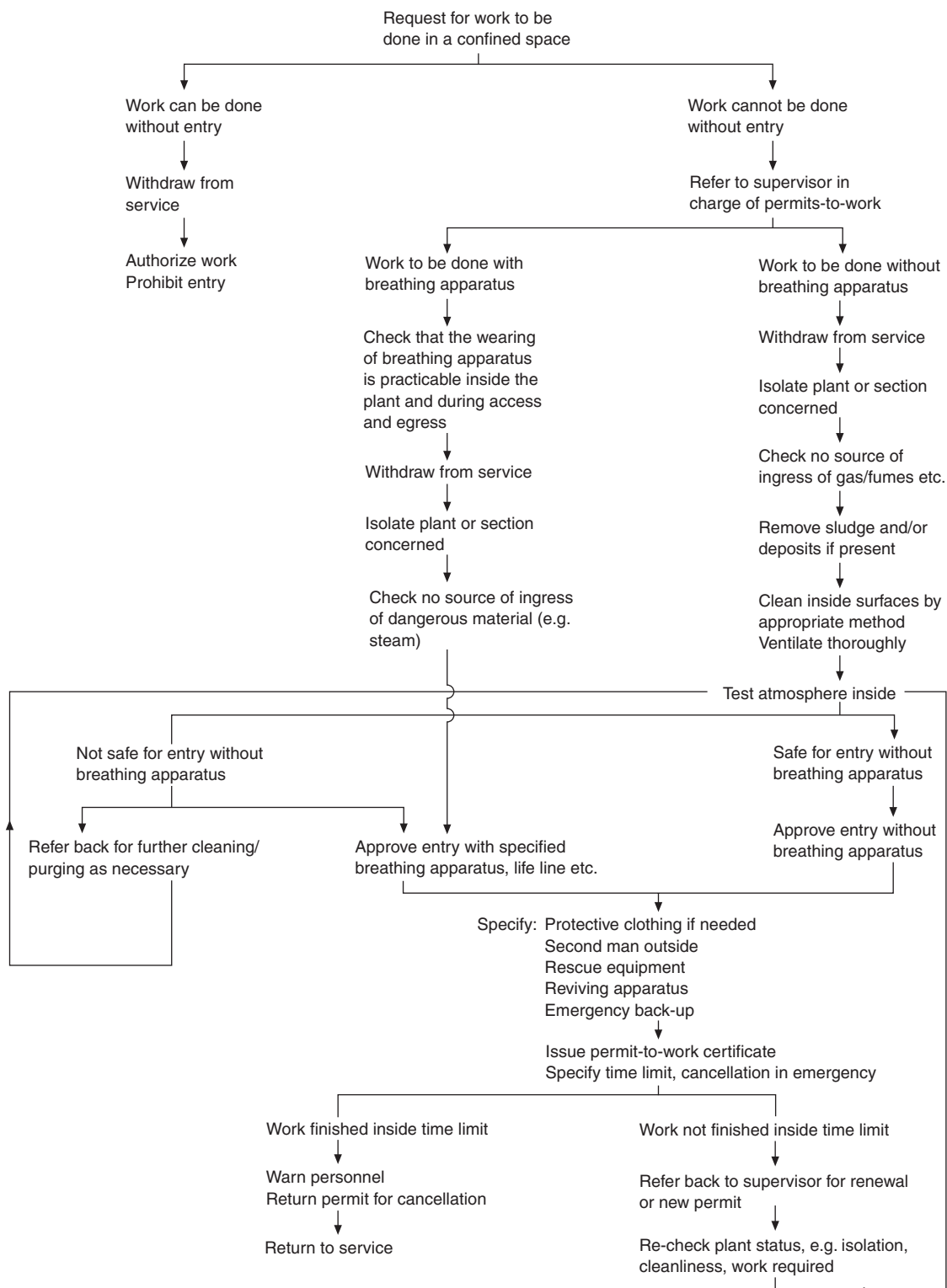


**Figure 13.1** Procedure for entry into a confined space

**Table 13.3 Entry into confined spaces (see Figure 13.1)**

A permit-to-work system is essential to control entry into confined spaces, e.g. tanks, reactors or underground chambers.

**Requirements**

No entry without a specific permit-to-work authorizing the work; entry without a permit is forbidden except for rescue purposes

Strict compliance with all instructions on the permit, e.g. the wearing of breathing apparatus and other safety equipment; if a safety belt or harness is used, it must be attached to a lifeline, the free end of which is held by a person outside the confined space

If a person is appointed to hold the lifeline and to keep continual watch over the person within the confined space, it is forbidden to leave the post. It is necessary to be ready to summon help if required. (A specific emergency plan should be established)

Rescue of any person from a confined space where dangerous fumes, or an oxygen-deficient atmosphere, may be present is prohibited without wearing appropriate safety equipment

Application of a welding torch or burner to a tank or drum containing flammable material, either as solid, liquid or vapour or their residues, can cause an explosion. Such vessels, although apparently 'empty', may have residue in the bottom and/or in seams and crevices.

Heat should not be applied if cold methods, e.g. cold-cutting practices or cold-setting resins, can be used. Otherwise a permit-to-work system is required. Refer to Figure 13.3. The vessel must first be rendered safe, e.g. by thorough cleaning, using low-pressure steam or by boiling strong detergent solution, for  $\geq 30$  min. It must then be inspected internally; mirrors and torches can be used for this but any lights must be flameproof or intrinsically safe. An explosimeter can be used to check for vapour but will not detect solid residues or involatile liquid. Alternatively, the vessel may be filled with water or inert gas.

Do not:

- Attempt to drive off liquid using a naked flame;
- Assume that a vessel is clean without inspecting it;
- Rely upon blowing through with air or water washing;
- Use chlorinated solvents to remove residues.

The need to remove all flammable material from the area should be considered. Where this is impractical, checks on its containment and inerting are necessary, together with environmental monitoring to ensure that atmospheric levels are well below the lower explosive limit (Figure 13.3).

Other situations for which permits-to-work are required include:

Maintenance of apparatus used for microbiology.

Pipeline breaking, e.g. carrying chemicals, steam or those under pressure.

Work on high-voltage electrical supply, radioactive equipment, roof work such as checking toxic exhaust from ventilation outlets.

The isolation of certain mechanical equipment, e.g. conveyors, work on lifts, excavations, entry and positioning of cranes, isolation of various 'safety services', e.g. water or inert gas, stand-by power generation, water supply to sprinkler systems, compressed air for breathing apparatus.

Removal of potentially contaminated equipment to workshop for maintenance, introduction of non-flameproof electrical equipment into a classified area.

In general, any other work should be covered which the responsible manager considers non-routine and/or for which a special hazard exists.

|                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                            |  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| PLANT DETAILS<br>(Location identifying number, etc.)                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                            |  |
| WORK TO BE DONE                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                            |  |
| WITHDRAWAL<br>FROM SERVICE                                                                                                                                                                                                                                                                                                                                                     | The above plant has been removed from service and persons under my supervision have been informed<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                                |  |
| ISOLATION                                                                                                                                                                                                                                                                                                                                                                      | The above plant has been isolated from all sources of ingress of dangerous fumes, liquids, solids, etc.<br><br>Signed _____<br>The above has been isolated from all sources of electrical and mechanical power<br><br>Signed _____<br>The above plant has been isolated from all sources of heat<br><br>Signed _____ Date _____ Time _____ |  |
| CLEANING AND<br>PURGING                                                                                                                                                                                                                                                                                                                                                        | The above plant has been freed of dangerous materials<br><br>Material(s): _____ Method(s): _____<br>Signed _____ Date _____ Time _____                                                                                                                                                                                                     |  |
| TESTING                                                                                                                                                                                                                                                                                                                                                                        | Contaminants tested _____ Results _____<br>Signed _____ Date _____ Time _____                                                                                                                                                                                                                                                              |  |
| I certify that I have personally examined the plant detailed above and satisfied myself that the above particulars are correct<br>(1) The plant is safe for entry without breathing apparatus<br>(2) Approved breathing apparatus must be worn<br>Other precautions necessary:<br>Time of expiry of certificate: _____ Signed _____ Date _____ Time _____<br>Delete (1) or (2) |                                                                                                                                                                                                                                                                                                                                            |  |
| ACCEPTANCE OF<br>CERTIFICATE                                                                                                                                                                                                                                                                                                                                                   | I have read and understood this certificate and will undertake to work in accordance with the conditions in it.<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                  |  |
| COMPLETION OF<br>WORK                                                                                                                                                                                                                                                                                                                                                          | The work has been completed and all persons under my supervision, materials and equipment withdrawn<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                              |  |
| REQUEST FOR<br>EXTENSION                                                                                                                                                                                                                                                                                                                                                       | The work has not been completed and permission to continue is requested<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                                                          |  |
| EXTENSION                                                                                                                                                                                                                                                                                                                                                                      | I have re-examined the plant detailed above and confirm that the certificate may be extended to expire at:<br>Further precautions:<br><br>Signed _____ Date _____ Time _____                                                                                                                                                               |  |
| THE PERMIT TO WORK IS NOW CANCELLED. A NEW PERMIT WILL BE REQUIRED IF WORK IS TO CONTINUE<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                            |  |
| RETURN TO<br>SERVICE                                                                                                                                                                                                                                                                                                                                                           | I accept the above plant back into service<br><br>Signed _____ Date _____ Time _____                                                                                                                                                                                                                                                       |  |

**Figure 13.2** 'Permit-to-work' certificate for entry into a confined space. A certificate number is added for identification, authenticity checking etc.

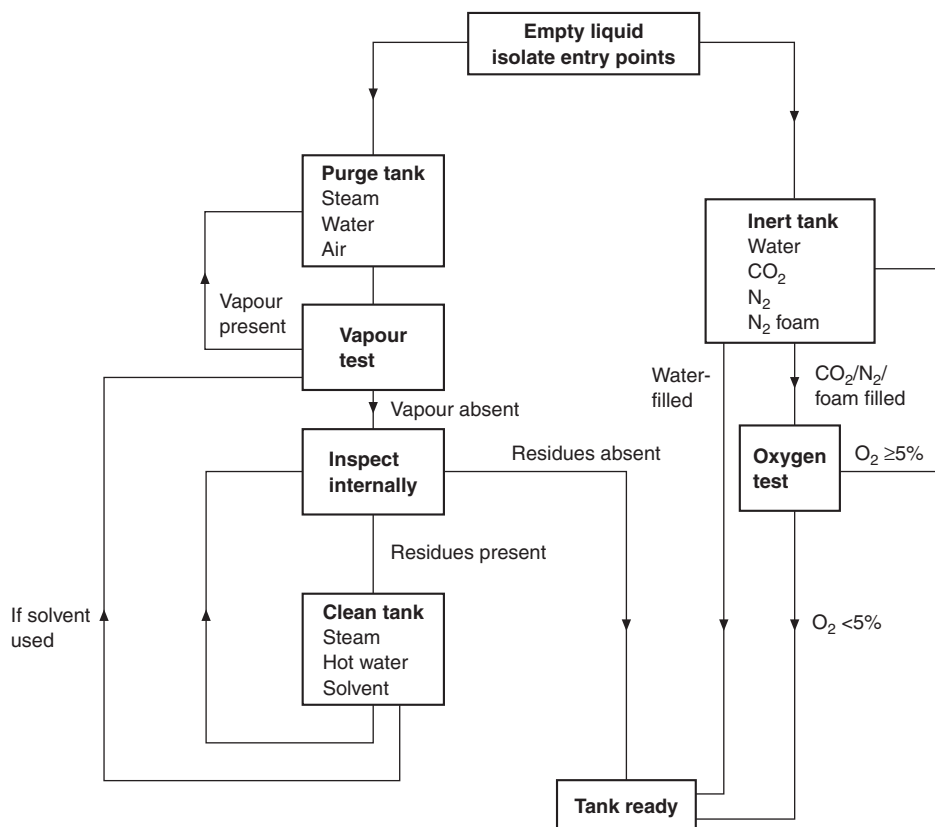


**Figure 13.3** Procedure for 'hot work' on equipment that contains, or has contained, a flammable chemical (general summary only: reference should be made to detailed procedures)

A permit should document:

The person issuing the permit and his/her position in the company.

The date/time on which the permit becomes effective.

The precise work to be done and specify unambiguously the plant items involved.

Precautions which have been taken and those which need to be observed during the work, including which apparatus or plant items have been made safe.

The associated outstanding risks with it.

Precautions to be taken on completion of the work, e.g. a fire-watch following welding in an area containing combustible solids.

The completion of the work.

The handback of plant from maintenance to production staff.

Thus operating personnel are responsible for ensuring that an area or plant item is isolated and free of danger; at the end of the work, maintenance staff are responsible for ensuring that any hazard that may have been introduced during their work has been removed and the plant etc. checked and shown to be safe prior to handback to operating staff. A checklist for the review of permit-to-work systems is given in Table 13.4 and Figure 13.4 illustrates a typical permit-to-work. Safety can only be guaranteed if all participants follow the permit conscientiously and

CERTIFICATE OF CONDITIONS AND RESPONSIBILITY OTHER THAN FOR ENTRY INTO VESSELS OR CONFINED SPACES  
Part 1

|                                                                                                                                                                                                                                                                                                                                       |                       |                          |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------|
| WORKS                                                                                                                                                                                                                                                                                                                                 | Certificate No.       |                          |
| DEPARTMENT                                                                                                                                                                                                                                                                                                                            | Date of issue         | Date .....<br>Time ..... |
| SECTION OF PLANT                                                                                                                                                                                                                                                                                                                      | Period valid to ..... |                          |
| CIRCUMSTANCES                                                                                                                                                                                                                                                                                                                         |                       |                          |
| NOTE: strike through where not applicable                                                                                                                                                                                                                                                                                             |                       |                          |
| (1) The above item of plant is isolated from every (dangerous) source of steam, gas, fume, liquid, solids, motive power, heat and electricity.<br>Details of isolation:                                                                                                                                                               |                       |                          |
| (2) The above item of plant is not isolated from every (dangerous) source of steam, gas, fume, liquid, solids, motive power, heat and electricity.<br>These special precautions must be taken in addition to (3) and (4) below.                                                                                                       |                       |                          |
| (3) Naked Flame or Other<br>Source of Ignition                                                                                                                                                                                                                                                                                        | Not<br>Permissible    | Permissible: Type:       |
| (4) Other hazards which may be encountered                                                                                                                                                                                                                                                                                            |                       | Precautions              |
| <div style="display: flex; justify-content: space-between;"> <div> Hand over<br/> Issuing Dept ..... Date .....<br/> (Signature) Time .....<br/> Receiving Dept. ....<br/> (Signature) </div> <div> Hand Back<br/> Issuing Dept ..... Date .....<br/> (Signature) Time .....<br/> Receiving Dept. ....<br/> (Signature) </div> </div> |                       |                          |

AUTHORIZATION TO WORK OTHER THAN IN VESSELS OR CONFINED SPACES  
Part 2

|                                                              |                       |                          |
|--------------------------------------------------------------|-----------------------|--------------------------|
| WORKS                                                        | Authorization No.     |                          |
| DEPARTMENT                                                   | Date of issue         | Date .....<br>Time ..... |
| SECTION OF PLANT                                             | Period Valid to ..... |                          |
| Certificate No.                                              |                       |                          |
| (1) Work to be carried out.                                  |                       |                          |
| (2) The following precautions have been taken.               |                       |                          |
| (3) Naked Flame or Other<br>Source of Ignition               | Not<br>Permissible    | Permissible Type:        |
| (4) Precautions to be taken in addition to (2) and (3) above |                       |                          |
| Work may start .....<br>(Signature)                          |                       | Date .....<br>Time ..... |
| Work completed .....<br>(Signature)                          |                       | Date .....<br>Time ..... |

**Figure 13.4 (facing page)** 'Hot work' permit. Part 1 records conditions and steps required; Part 2 authorizes work and specifies precautions.

*This type of certificate may be designed to cover work on roofs, in storage bunkers and on plant containing gas, fume, steam or corrosive, poisonous or radioactive materials; welding and burning in potentially hazardous areas; work being carried out where there is a risk of fire, explosion, electric shock, flooding or high pressure. It is not considered appropriate for work on electrical equipment operating at >650 V.*

without short cuts. Only one permit relating to one piece of equipment should be allowed at any one time. Best practice is for only one person to have authority to issue permits for a specific area. These permits should be cross-referenced and collected.

**Table 13.4 Checklist for permit-to-work systems**

---

|                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Are staff trained in the use of the permit-to-work system and its significance?                                                                                                                 |
| Is it clearly laid down who should issue permits and to whom?                                                                                                                                   |
| Is the system audited regularly?                                                                                                                                                                |
| Does each permit clearly identify the work to be done and the hazards associated with it?                                                                                                       |
| Does each permit state the precautions which have been taken and those needed while the work is in progress (e.g. isolations, purging, personal protective equipment)?                          |
| Is there a system of clear cross-referencing when two or more jobs subject to permits may affect each other?                                                                                    |
| Does each permit have a hand-back procedure which incorporates statements that the maintenance work has finished and that the plant has been returned to production staff in a safe condition?  |
| Are time limits included, and shift changeovers covered?                                                                                                                                        |
| Is it clear what procedures to follow if work is suspended for any reason?                                                                                                                      |
| Is the permit form clearly laid out, avoiding statements or questions which could be misleading or ambiguous, but being sufficiently flexible for use in 'unusual' circumstances, however rare? |
| Does the system cover contractors?                                                                                                                                                              |
| Is a copy of the permit on clear display in the work area?                                                                                                                                      |
| Have signatories of permits been trained?                                                                                                                                                       |

---

## Pressure systems

The safety of pressure systems in Great Britain is controlled by the Pressure System Safety Regulations 2000. These probably apply if

- (a) the plant contains relevant fluid (e.g. steam, compressed air or liquefied gas, or a gas dissolved under pressure in a solvent at ambient temperature and which could be released from the solvent without application of heating) at a pressure >0.5 bar above atmospheric,
- (b) there is a pressure vessel in the system *and*
- (c) the plant is used at work by employees and/or the self-employed.

All steam systems with a pressure vessel used at work are covered, irrespective of pressure.

### *Basic requirements*

Establish the safe operating limits of the plant.

Have a suitable written scheme drawn up or certified by a competent person for the examination at appropriate intervals of most pressure vessels and all safety devices, and any pipework which is potentially dangerous. Advice may be sought from any competent person when deciding what vessels and parts of the pipework need to be included.

Have examinations carried out by a competent person at the intervals set down in the scheme.  
Provide adequate operating instructions to ensure that the plant is operated within its safe operating limits, and emergency instructions.  
Ensure that the plant is properly maintained.  
Keep adequate records of the most recent examination and any manufacturer's records supplied with new plant.

Here the safe operating units are basically the upper limits of pressure and temperature for which the plant was designed to be operated safely.

## Emergency procedures

Emergencies include controllable events leading to safe shutdown of the plant and uncontrollable emergencies. The first can escalate into more serious and uncontrollable emergencies. Emergency planning is necessary to cover a wide range of eventualities. Within the UK procedures are required under the Management of Health and Safety at Work Regulations 1992 and, in specific cases, the COMAH Regulations 1999.

### *Minor emergencies*

Personal injuries (refer to Table 13.8 for chemicals).  
Small fires (refer to Table 6.15).  
Overpressures, even if vented.  
Spillages, etc, e.g. onto land, into drains, into controlled water.  
Process 'excursions', e.g. temperature, pressure.  
Equipment failure.  
Disruption of essential services or computer networks.

### *Major emergencies*

Fire with or without potential for escalation.  
Explosion.  
Toxic releases.  
Flammables release (unignited).  
Large spillage.  
Pollution episode, on or off site.  
Person trapped in vessel/confined space.  
Multiple casualties.  
Emergency on adjacent site (mutual aid).  
Others (credible events, coincident emergencies).

However, most detailed planning tends to relate to major incidents, or those which might affect the public or neighbouring sites.

Any on-site emergency plan will be site- and business-specific. It should provide simple and logical procedures for effective direction and coordination of an emergency incident in a way which

safeguards personnel including rescuers, fire-fighters, etc.;  
deals with casualties;

- minimizes damage to plant and equipment, buildings, and materials/stock;
- prevents escalation;
- triggers off-site responses, e.g. fire service, ambulance service, police, specialized staff;
- minimizes off-site effects of pollution; and
- restores the site to normal operation as rapidly as possible.

An inherent part of planning is to ensure that all personnel fully understand their own role, and appreciate the roles of others, in dealing with an emergency. In some situations it will be important to recover records, equipment and samples for subsequent investigation.

## ***Warnings***

A primary consideration is the method of warning that an emergency has occurred. Whether this involves bells, sirens, horns etc.,

The alarm must be audible to everyone.

Everyone must know what it means, and the correct action to take.

Visual alarms may be required in locations with a high level of background noise. Different alarms may be provided to warn of different emergencies, e.g. a minor fire, a toxic release or an incident requiring complete evacuation.

On a small site an emergency is likely to affect the complete site; hence a common warning system is required. On a very large site a two-tier warning system may be used, i.e. a local warning which differs from a warning to the whole complex.

## ***Incident categorization***

There are four typical categories of emergency.

A *minor incident* is one capable of being dealt with fairly effectively and quickly by personnel on the spot using the emergency equipment, e.g. fire extinguishers and monitors, on hand. The situation can be dealt with by the workforce, possibly including a Works Fire Brigade, fairly rapidly. It is reasonably localized and no other unit is affected.

A *Category 1 incident* is one requiring additional resources, but which can be dealt with by the site operator and internal fire brigade. Some thought needs, however, to be given as to whether, and when, the public emergency services should be notified. (The incident could escalate and result in the personnel on site requiring assistance quickly. If the total site forces are fully occupied dealing with a protracted incident, back-up resources may be needed to guard against a second incident.)

A *Category 2 incident* is one clearly recognizable from the outset as beyond the capability of the forces to hand. The emergency services should be informed immediately of the magnitude of the incident and the specific location. The resources sent in response, e.g. the number of fire appliances, ambulances, police, need to be predetermined by good pre-planning.

A *Category 3 incident* is an emergency of major proportions. It may have escalated from a smaller incident or arise instantaneously, e.g. due to a confined or unconfined vapour cloud explosion or a catastrophic failure of a storage vessel. The response from the emergency services will again need to be predetermined by pre-planning. Extensive evacuation of the general public may be required.



### *Calling in staff*

When an emergency develops it may be necessary to call in key personnel, e.g.

- Staff able to continue operation of the plant or shut it down safely.
- Management who can take top-level decisions.
- Staff able to deal with the aftermath of casualties.
- Public relations staff to deal with the media.

Pre-planning may therefore include preparation of a 'call-in' list with the proviso that 90% of personnel will respond when called.

### *Responsibilities and pre-planning*

Each person in the emergency team should understand clearly, and be well-practised in, the function that they have to perform.

One person, e.g. a Shift Manager, will have responsibility for responding immediately to an incident and for taking charge.

The priorities are:

- 1 Rescue of personnel, where appropriate; assessment of whether there are casualties or whether people may be missing and should be searched for.
- 2 Carrying out appropriate process action so that the situation does not escalate further.
- 3 Ensuring that the fire brigade, or other personnel trained in initial first aid/fire-fighting, are present.
- 4 Initiating some form of 'head-count'. In some situations provision is obviously necessary for wardens or properly equipped rescuers to search areas to ensure evacuation is complete.

Accounting for staff can be difficult; hence the advantage of site logging-in procedures. Instructions should be posted, stating

Where personnel should go, by which route/alternative routes in an emergency.

To whom they should report on arrival.

What to do if they are unable to go to the nominated assembly point. (Different assembly points may be appropriate for different incidents, e.g. a fire in a specific area, a potential explosion or a spillage.)

Effective management of an emergency depends upon pre-planning, including:

Provision of an adequately equipped emergency control centre of suitable design located outside potential danger zones.

Procedures for the rapid assessment of the likely consequences in the event of, e.g., loss of containment of a hazardous material (identify the nature and quantity of material lost, check wind direction, determine from a map probable areas to be affected and the likely population density threatened).

Provision of sets of process manuals, flowsheets, plot plans etc., ready for immediate use.

Lists of mechanical equipment available, e.g. diggers, cranes, lifting equipment, and of emergency supplies, e.g. sand, wood, sandbags, drainseals, pipeblockers and absorbents for spillages on the ground and in drainage systems; floating booms for immiscible liquids (s.g. <1.0) that enter waters, and skimmers.

Provision for monitoring and sampling, e.g. of oxygen levels, combustible gases and airborne toxic substances and the taking of samples from air, water and ground.

Provision of action lists, list of emergency contacts and phone numbers, details of location of specialist services and equipment.

Provision of simple refreshment facilities.

Provision for dealing with emergency services and personnel responding from outside, e.g. designated locations for ambulances, fire appliance reception points, emergency services reporting points, vehicle parking.

External liaison, e.g. to give essential personnel and the emergency services easy access to the site by the correct route, and to deal with the media.

## ***Communications***

Provisions for primary and emergency communications (internal, e.g. with staff, emergency personnel, and external, e.g. with the press, emergency services, hospital, employees' relatives, telephone links and radios) require careful assessment. If there is a flammable hazard on site, radios may need to be intrinsically safe or flameproof.

## ***Training and exercises***

Every part of an emergency plan has to be understood by all personnel involved, including the emergency services. Detailed instructions therefore have to be issued to all those who will act to control, or mitigate the effects of, a major incident. Everyone on site needs to understand the plan and the procedures in it; this includes:

Familiarity with the different alarms, e.g. so as not to confuse a process plant alarm for a fire/toxic gas release signal.

Familiarity with the actions to take, escape routes, assembly areas.

Thorough training, including realistic practical exercises, with participation of outside services, is advisable. A full-scale rehearsal at least once a year is recommended. (Modifications can subsequently be introduced to cater for reported errors and omissions.)

## ***Off-site requirements***

Plans are also necessary to deal with the possible impact of accidents off-site. An indication of what these may entail is provided by the minimum information, listed in Table 13.5, which the occupier of a COMAH site must supply to the local authority to enable them to draw up an off-site emergency plan.

## **Spillage**

All chemical spillages should be dealt with immediately since they may:

Pose corrosive, or skin absorbent hazards.

Pose flammable or toxic hazards (e.g. by inhalation or ingestion), or affect the eyes, mucous membranes or skin, especially if spillage involves volatile liquids in confined spaces, or if dust can become airborne.

**Table 13.5 Minimum information to be supplied to local authority for an off-site emergency plan under the COMAH Regulations**


---

Details of site, location, nearby roads, site access.  
 Site plan.  
 Staffing levels.  
 Off-site areas likely to be affected by major accidents and estimates of levels of harm which might result.  
 Details of dangerous substances on site covered by the COMAH Regulations and of other hazardous materials on site.  
 Details of technical advice the company can provide to assist an emergency response.  
 Technical details of equipment and other resources normally available on-site and which may be available to assist the off-site emergency services.  
 The functions of key posts with duties in the emergency response, their location and identification.  
 An outline of the initial actions and procedures in the on-site emergency plan.

---

Create slippery conditions (e.g. detergents, oils).  
 Contaminate other materials/processes.  
 Be symptomatic of more serious deficiencies in safety.  
 Create risk of pollution.  
 Be of nuisance value.

In general, systems of work should prevent spillages; nevertheless accidents will occur. As with accidents requiring first aid (see page 429), arrangements for dealing with spillages should be planned prior to the introduction of chemicals into the site. Bunds should be provided to contain spillage of hazardous substances. Procedures for cleaning up dangerous spillages will be dictated by circumstances (e.g. for mercury see page 157). Actions include:

Assess the risk (e.g. identify the chemical and its hazardous properties, note the scale and prevailing circumstances); where necessary, raise the alarm, evacuate the area, obtain assistance etc.  
 Don appropriate personal protection and, where it is safe to do so, contain the spillage (e.g. with sheets, pillows, booms, sand); if necessary, provide ventilation.  
 Clean the spillage using appropriate clean-up material (sand, clay granules, cloth rags, synthetic sorbents, oil sorbents, general-purpose sorbents of high liquid-retention capability).  
 Reassess risk, if necessary by environmental monitoring, swab tests.

Liquid spillages may be sucked up by pump and non-toxic solids can be vacuumed or brushed up (after wetting down where appropriate). Only small quantities of inert, water-soluble waste should be discarded to drains; acids and alkalis should first be neutralized.

Equipment to deal with spillages is summarized in Table 13.6. Treatment may require some combination of the measures given in Table 13.7.

Emergencies involving spillages during transport are mentioned in Chapter 15.

**Table 13.6 Equipment for treatment of 'small' spillages, e.g. in a laboratory**


---

Rubber or plastic gloves, face shields or goggles, rubber boots or over-shoes, face masks and an 'all-purpose' respirator  
 Household dustpan (rubber or polythene), brush and large bucket (preferably polythene), an ordinary steel shovel, stiff bristle brush and a soft brush, for sweeping up and containing broken glass, and industrial cotton mops, plastic foam mops or squeegees  
 Soap or detergent or special non-flammable dispersing agent to reduce fire hazards from flammable spillage and to reduce nuisance from lachrymators and strong-smelling fluids; disinfectants for biological smells  
 Sand in bucket or absorbents

---

**Table 13.7 Procedure to treat spillages in a laboratory**


---

|                                                                                                                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Instruct others to keep a safe distance                                                                                                                                                                                                                    |
| Remove contaminated clothing and wash the hands before putting on protective clothing                                                                                                                                                                      |
| Shut off all sources of ignition (for spillage of flammable fluid); do not operate electric switches in the vicinity                                                                                                                                       |
| Ventilate the area well (for at least 10 min) to reduce irritant vapours and biological aerosols, and to evaporate remaining liquid (bear in mind that ventilation may transfer the danger to other parts of the premises)                                 |
| Areas with sealed windows should have controlled ventilation (areas that cannot be adequately ventilated are unsuitable for use with hazardous materials)                                                                                                  |
| Turn off the source of the leak and limit the spread of fluid by means of mop, dusters, rags, sand or diversion                                                                                                                                            |
| Absorb spillage and shovel into buckets, and remove to a safe place, dilute greatly with running water and/or dilute with dispersing agent and water (as with ammonia solution, ethanol, methanol and formaldehyde solution)                               |
| Neutralize acid with soda ash, chalk or similar materials kept for the purpose, mop up cautiously with water (in case local areas of concentrated acid have been missed)                                                                                   |
| Use hypochlorite solutions in excess scattered over spillage of cyanide solutions and wearing respirator and gloves, mop up and collect in buckets. Allow to stand for 24 hours before diluting greatly and running to waste                               |
| Flood with a phenolic disinfectant any biologically contaminated area for 30 to 60 min and then clean up with water and allow to dry. After cleaning up wash hands with a suitable skin disinfectant (such as 0.5% Chlorhexidine in 70% methylated spirit) |
| Use forceps or a brush and pan with broken glass; never use the fingers, even with gloves. Disinfect broken glass arising from biological spills                                                                                                           |
| Dispose of, by special arrangements, chemicals which cannot be admitted to the public sewerage system, e.g. flammable liquids and reagents with high toxicity                                                                                              |

---

## First aid

In Great Britain the Health and Safety (First Aid) Regulations 1981 require an employer to provide such equipment and facilities as are adequate and appropriate in the circumstances to enable first aid to be rendered to his employees if they are injured, or become ill, at work. An Approved Code of Practice gives more specific details on the number of first-aid personnel and their training, and the type of equipment.

### *Emergency first aid*

A qualified first-aider, or nurse, should be called immediately to deal with any injury – however slight – incurred at work.

Any person on the spot may have to act immediately to provide first-aid treatment to prevent deterioration in the injured person's condition until assistance arrives. The aims are:

- To sustain life.
- To minimize danger.
- To relieve pain and distress.

Check the situation for danger to rescuers, then act as follows:

|              |                  |                                                                                           |
|--------------|------------------|-------------------------------------------------------------------------------------------|
| The patient: | is in danger     | Remove from danger, or remove the danger from the patient                                 |
|              | is not breathing | If competent to do so, give artificial ventilation. Otherwise send for help without delay |
|              | has no pulse     | Start cardiac compressions                                                                |
|              | is bleeding      | Stop bleeding                                                                             |

|                               |                                                                                                                                                                                                                                                                                         |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| is unconscious                | Check the mouth for any obstruction. Open the airway by tilting the head back and lifting the chin using the tips of two fingers. If this does not keep the airway open, turn the casualty into the recovery position i.e. turn on side and ensure they cannot roll over; lift the chin |
| feels faint                   | Lie him or her down                                                                                                                                                                                                                                                                     |
| has broken bones              | Immobilize. Do not move the patient unless he/she is in a position which exposes them to immediate danger. Obtain expert help                                                                                                                                                           |
| has open wounds               | After washing your hands, if possible cover with a dressing from the first-aid box. Seek appropriate help                                                                                                                                                                               |
| has thermal or chemical burns | Immerse or flood copiously with cold water for $\geq 10$ min                                                                                                                                                                                                                            |
| has minor injuries            | Ignore these if there are more serious ones                                                                                                                                                                                                                                             |
| is poisoned                   | Small amounts of water may be administered, more if the poison is corrosive. Administer a specific antidote if one exists. Do not induce vomiting.                                                                                                                                      |

### *Cuts*

All minor cuts should be cleaned thoroughly and covered with a suitable dressing. After controlling bleeding, if there is a risk of a foreign body in the wound do not attempt to remove it, but cover loosely and take patient to a doctor or hospital, as should be done if there is any doubt about the severity of the wound.

### *Burns/scalds*

Burns may arise from fire, hot objects/surfaces, radiant heat, very cold objects, electricity or friction. Scalds may arise from steam, hot water, hot vapour or hot or super-heated liquids.

The affected area should be cooled by holding in cold, clean running water. Swelling is liable to occur so jewellery or clothing likely to cause constriction must be removed. The area should then be covered with a sterile dressing, care being taken to apply the dressing without it sticking to the burned area. Blisters should not be pricked or damaged and cream or lotions should be avoided.

The patient may suffer from shock, in proportion to the extent of the injury. Give small drinks and keep warm: do not overheat. In all cases, speed of treatment is crucial to limit the effects of burns. Flowcharts which summarize the initial procedures for electrical, thermal and chemical burns respectively are shown in Figure 13.5.

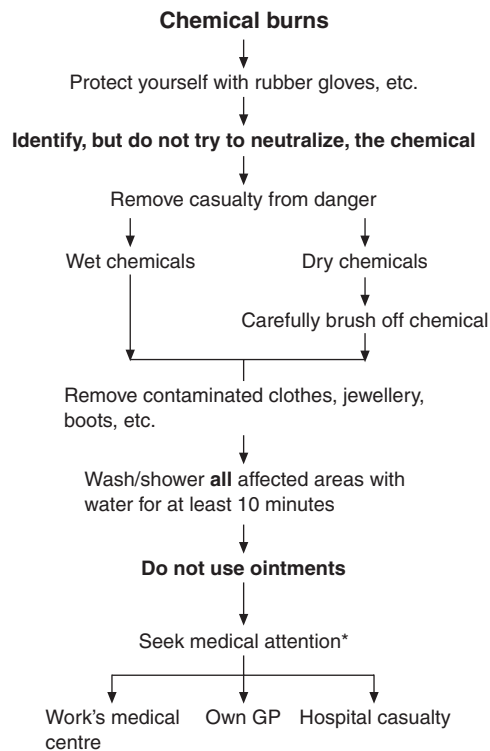
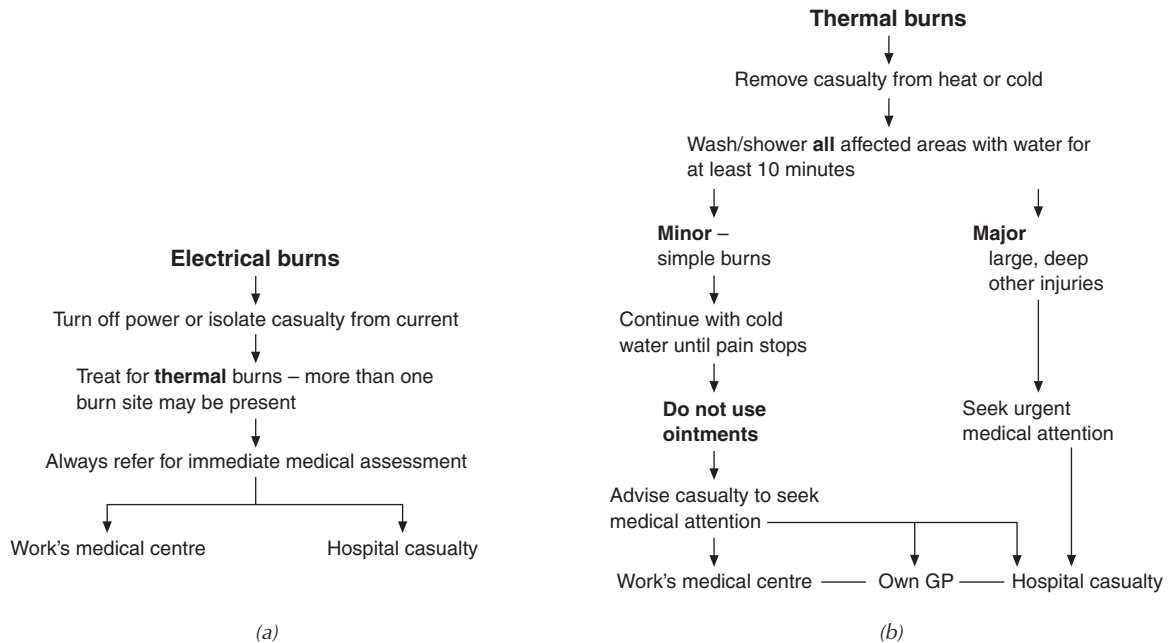
### *Chemical splashes, poisoning by ingestion*

Refer to Table 13.8.

All cases of ingestion should be referred to a doctor and/or hospital without delay.

### *Antidotes*

Effective antidotes for use in an emergency are not common. Examples include:



\* Material Safety Data Sheets should accompany casualty in every case.

(c)

**Figure 13.5** Initial procedures for dealing with burn injuries

Table 13.8 Standard first aid treatments for chemical exposure

|                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Splashes on the skin</b>            | <p>Flood the splashed surface thoroughly with large quantities of running water for ≥10 min or until satisfied that no chemical remains in contact with the skin</p> <p>Use soap to help remove splashes of solvents, solutions and chemicals known to be insoluble in water</p> <p>Remove all contaminated clothing, taking care not to contaminate yourself in the process</p> <p>If necessary, arrange for transport to hospital or refer for medical advice to nearest doctor</p> <p>Information to accompany the casualty:</p> <p>Chemical involved</p> <p>Details of treatment already given</p> <p><i>(Special procedures apply to certain chemicals, e.g. anhydrous hydrogen fluoride, aqueous hydrofluoric acid, phenol and related compounds)</i></p> |
| <b>Splashes in the eye</b>             | <p>Flood the eye thoroughly with large quantities of clean, cool water or sterile liquid from a sealed container and continue for 10–15 min</p> <p>Ensure that the water bathes the eyeball by gently prising open the eyelids and keeping them apart until treatment is completed. Do not attempt to remove anything that is embedded</p> <p>All eye injuries from chemicals require medical advice. Apply an eye pad and arrange transport to hospital</p> <p>Information to accompany the casualty:</p> <p>Chemical involved</p> <p>Details of treatment already given</p>                                                                                                                                                                                   |
| <b>Inhalation of gas</b>               | <p>Remove the casualty from the danger area after first ensuring your own safety</p> <p>Loosen clothing; administer oxygen if available</p> <p>If the casualty is unconscious, place in the recovery position and watch to see if breathing stops</p> <p>If breathing has stopped, apply artificial respiration by the mouth-to-mouth method; if no pulse is detectable, start cardiac compressions</p> <p>If necessary, arrange transport to hospital</p> <p>Information to accompany the casualty:</p> <p>Gas involved</p> <p>Details of treatment already given</p> <p><i>(Special procedures apply to certain chemicals, e.g. hydrogen cyanide)</i></p>                                                                                                     |
| <b>Ingestion of poisonous chemical</b> | <p>If the chemical has been confined to the mouth, give large quantities of water as a mouthwash; ensure that the mouthwash is not swallowed</p> <p>If the chemical has been swallowed, small amounts of water may be administered, more if the chemical is corrosive; administer a specific antidote if one exists</p> <p>Do not induce vomiting</p> <p>Arrange transport to hospital</p> <p>Information to accompany the casualty:</p> <p>Chemical swallowed</p> <p>Details of treatment already given</p> <p>Estimate of quantity/concentration of chemical consumed</p>                                                                                                                                                                                     |

*for cyanide poisoning.* Intravenous injection of:

- 3% Sodium nitrite and 50% sodium thiosulphate.
- Cobalt EDTA.

*for HF on the skin.* Application of magnesium oxide paste with injection of calcium gluconate below the affected area.

*for splashes of phenols.* Apply alcohol-soaked swabs.

Where there is a specific antidote suitable for emergency use it should be kept available and appropriate personnel trained in its use. Specific training should be given to first-aiders over and above their general training if they may need to administer oxygen or deal with incidents involving hydrogen cyanide, hydrofluoric acid or other special risks.

## ***Records***

Any injuries or cases of illness treated should be recorded. The minimum details are:

- Date, time and place of incident/treatment.
- Name and job of casualty.
- Details of injury/illness and of treatment.
- Subsequent movements of casualty (i.e. returned to work, sent home, sent to hospital, etc.).
- Name and signature of person providing treatment.

## **Personal protection**

Because personal protection is limited to the user and the equipment must be worn for the duration of the exposure to the hazard, it should generally be considered as a last line of defence. Respiratory protection in particular should be restricted to hazardous situations of short duration (e.g. emergencies, maintenance, or temporary arrangements while engineering control measures are being introduced). Occasionally, personal protection may be the only practicable measure and a legal requirement. If it is to be effective, its selection, correct use and condition are of paramount importance. (Therefore within the UK the Personal Protective Equipment at Work Regulations 1992 require the provision of suitable p.p.e. except where and to the extent that a risk to health and safety is adequately controlled by other means. This has to be maintained, which covers: replacement or cleaning and keeping in an efficient state, in efficient working order and in good repair.)

### ***Respiratory protection***

Recommendations for the selection, use and maintenance of respiratory protective equipment are provided in the UK by BS 4275 1997 and BS EN 132. The two basic principles are:

- purification of the air breathed (respirator) *or*
- supply of oxygen from uncontaminated sources (breathing apparatus).

If the oxygen content of the contaminated air is deficient (refer to page 72), breathing apparatus is essential. The degree of protection required is determined by the level of contamination, the hygiene standard for the contaminant(s), the efficiency of any filter or adsorber available, and the efficiency with which the facepiece of the device seals to the user's face (this is reduced by beards, spectacles etc.). The level of comfort and user acceptability are further considerations.

The nominal protection factor (NPF) describes the level of protection afforded by a specific respirator:

$$\text{NPF} = \frac{\text{Concentration of contaminant in air}}{\text{Concentration of contaminant inside facepiece}}$$

The British Standard also uses the Assigned Protection Factor, i.e. the level of respiratory protection that can realistically be expected to be achieved in the workplace by 95% of adequately trained and supervised workers, using a properly functioning and correctly fitted respiratory protective device (see Table 13.9)



**Table 13.9 Assigned Protection Factors for Respirators and Breathing Apparatus**

| Type                                                                                                                                                                                                                                                                                                                 | APF (depending upon detailed equipment specification) |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| <b>1 Filtering devices</b><br>Half or quarter mask and filter<br>Filtering half-mask without inhalation valves<br>Valved filtering half masks<br>Filtering half masks<br>Full face mask and filter<br>Power assisted filtering device with full, half or quarter masks<br>Power filtering device with helmet or hood | <b>4–40</b>                                           |
| <b>2 Breathing apparatus</b><br>Light duty construction air line<br>Fresh air hose and compressed air line<br>Self contained                                                                                                                                                                                         | <b>10–2000</b>                                        |

### *Gas masks (canister or cartridge mask)*

Respirators for gases and vapours comprise a facepiece and a container filled with a specific adsorbent for the contaminant. Care must be taken to select the correct type. More than one canister can be attached.

The useful life of a canister should be estimated based on the probable concentration of contaminant, period of use, breathing rate and capacity of the canister.

### *Dust and fume masks*

Dust and fume masks consist of one or two cartridges containing a suitable filter (e.g. paper or resin-impregnated wool) to remove particulate contaminant. The efficiency of the filters against particles of various sizes is quoted in manufacturers' literature and national standards. Such masks do not remove vapour from the air.

Facepiece fit is the limiting factor on the degree of protection afforded. Efficiency tends to increase with use, i.e. as the filter becomes loaded, but the resistance to breathing also increases. 'Paper cup' type masks are also available.

### *Powered dust masks*

Masks are available with battery-powered filter packs which supply filtered air to a facepiece from a haversack filter unit. Another type comprises a protective helmet incorporating an electrically operated fan and filter unit complete with face vizor and provision for ear muffs.

### *Breathing apparatus*

Compressed airline system: a facepiece or hood is connected to a filter box and hand-operated regulator valve which is provided with a safety device to prevent accidental complete closure. Full respiratory, eye and facial protection is provided by full-facepiece versions. The compressed air is supplied from a compressor through a manifold or from cylinders.

Self-contained breathing apparatus is available in three types:

Open-circuit compressed air.

Open-circuit oxygen-cylinder, liquid or solid-state generation.  
Regenerative oxygen.

All respiratory protective systems should be stored in clean, dry conditions but be readily accessible. They should be inspected and cleaned regularly, with particular attention to facepiece seals, non-return valves, harnesses etc. Issue on a personal basis is essential for regular use; otherwise the equipment should be returned to a central position. Records are required of location, date of issue, estimated duration of use of canisters etc.

Guidance on the choice of respiratory protection for selected environments is given in Figure 13.6. All persons liable to use such protection should be fully trained; this should cover details of hazards, limitations of apparatus, inspection, proper fitting of facepiece, testing, cleaning etc.

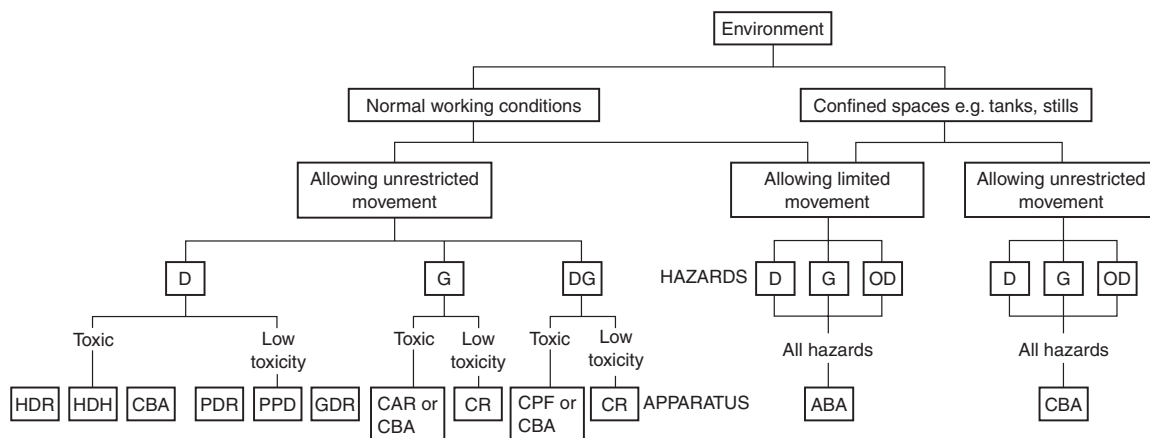


**Figure 13.6** Guide to the selection of respiratory protection

| Hazards              | Equipment                                                             |
|----------------------|-----------------------------------------------------------------------|
| D Dust               | ABA Air line breathing apparatus                                      |
| G Gas                | CAR Canister respirator                                               |
| DG Dust and gas      | CBA Self-contained breathing apparatus                                |
| OD Oxygen deficiency | CPF Canister respirators with particulate filters                     |
|                      | CR Cartridge respirator                                               |
|                      | GDR General purpose dust respirators                                  |
|                      | HDH High efficiency dust respirators                                  |
|                      | HDR Positive pressure direct dust hoods and blouses (high efficiency) |
|                      | PDR Positive pressure powered dust respirators                        |
|                      | PPD Positive pressure powered dust hood and blouses                   |

## Eye protection

The common-sense approach to the use of eye protection, includes:

- Eye protectors and/or fixed shields provided according to the nature of the process.
- Eye protectors on personal issue.
- Replacement of lost, defective or unsuitable eye protectors.
- Eye protectors suitable for individual needs.
- Eye protectors and shields that conform to an appropriate, approved specification and are marked to indicate intended use.

There are also requirements relating to the proper use and care of eye protectors/shields.

The normal range of personal eye protection is summarized in Table 13.10. In the UK the appropriate standard is BS EN 167, 168, 175 and BS 7028. Fixed shields can be of polycarbonate plastic to guard against splashing and projectiles, or of toughened glass or Perspex for protection against splashing only. Wrap-around of the hazard is required. If the need for access behind a shield cannot be eliminated personal protection is still necessary.

**Table 13.10 Normal range of personal eye protection**

|                                    |                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Safety spectacles</b>           | A variety of styles and colours are available with different side-shields to protect against lateral hazards<br>Attention must be given to both the lens (available toughened/tinted/to personal prescription for wearers requiring corrected vision) and the frame                                                                                            |
| <b>Cup and wide-vision goggles</b> | Tend to be more versatile and cheaper and offer more protection and, according to design, can protect against fine dust, fumes, liquid splashes and impact from flying particles<br>Tend to be less comfortable than safety glasses and usually cannot be worn over ordinary spectacles<br>Often mist up and as a rule are not fitted with prescription lenses |
| <b>Face shields</b>                | Intended to protect from the forehead to the neck<br>Some are attached to headgear and equipped with a chin-guard to prevent upward splashing of acids/alkalis<br>The transparent screen is commonly made of polycarbonate<br>Heavier special versions are available, e.g. for welding                                                                         |

## ***Head protection***

Head protection is required against falling objects but also serves against heat, chemical splashes, or entanglement of hair in machinery. The appropriate standard is BS EN 397 (1995).

Common-sense guidelines can be deduced from the requirements for 'building operations' and 'works of engineering construction' summarized in Table 13.11. In special situations, e.g. for fire-fighting or protection against toxic chemicals, hoods and suits cover the head and neck and many incorporate protection.

**Table 13.11 Head protection requirements for construction activities (Construction (Head protection) Regulations 1989)**

|                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------|
| Provision, maintenance and replacement whenever necessary                                                                            |
| Regular checking/replacement                                                                                                         |
| Protection to be adequate, e.g. to BS EN 397 or equivalent standard (Type 1 helmets with comfort options strongly recommended)       |
| Protection to be compatible with the work/activity of the wearer                                                                     |
| Protection to be worn at all times unless there is no risk from falling objects or possibility of hitting the head against something |
| Wearing of safety helmets to be ensured                                                                                              |

## ***Hand protection***

Protection of the hands may rely upon gloves or barrier creams. The choice of gloves depends upon:

Hazard to be protected against, e.g. corrosive or irritant chemicals, heat, abrasion.

Degree of resistance required.

Sensitivity required.

Area to be protected, e.g. to wrist level or extending over the forearms.

For applications where surgical gloves provide adequate protection, if these are of natural rubber latex then powder-free gloves with low/undetectable protein and allergen levels are advisable. (Alternatively the use of nitrile gloves eliminates the risk of latex allergy.)

General advice on the suitability and degree of resistance of glove materials are summarized in Table 13.12. In all cases, however, in addition to the necessary mechanical properties (i.e. resistance to abrasion, blade cut resistance, tear resistance and puncture resistance rated according to European Standard EN 388), consideration should be given to the resistance to the specific chemicals involved.

Chemical permeation is rated in tests under EN 374-3. The breakthrough time of a chemical through a glove is quoted as a permeation index:

| Breakthrough time (min) |    |    |    |     |     |     |
|-------------------------|----|----|----|-----|-----|-----|
| Greater than            | 10 | 30 | 60 | 120 | 240 | 480 |
| Permeation index        | 1  | 2  | 3  | 4   | 5   | 6   |

If the time <10 minutes the index is 0. Clearly the greater the index the better the resistance to permeation.

Some glove suppliers also provide data on, or a noting of, degradation, i.e. the physical effects which a chemical will have upon a particular glove material.

Resistance to penetration by micro-organisms is covered by EN 374-2 and protection from low temperatures in EN 511. Careful handling and regular inspection are essential since chemicals and abrasion will eventually cause deterioration of gloves. Rinsing in clean water and drying naturally will prolong their life.

Barrier creams are applied before work to provide a protective film. A different type of cream, cleansing cream, is applied after work to aid dirt removal and to condition skin with humectant.

### *Limitations of barrier creams*

They may become a reservoir for harmful chemicals.

Water-soluble preparations should not be used for aqueous situations; water-repellant creams are available for such applications.

There is a limit to the quantity of chemical a barrier cream can repel.

Effectiveness diminishes as a result of abrasion and massage.

They are unlikely to prevent an allergic contact dermatitis.

### ***Protective clothing***

Protective clothing includes overalls, bibs, duffle coats, aprons, complete one-piece suits with hoods, spats, armlets etc. It is chosen for protection against mechanical hazards, abrasion, extremes of temperature etc. as well as chemicals. The nature of the hazard and user comfort dictate the choice. The properties of a range of protective clothing materials are listed in Table 13.13. Further guidance on selection, use and maintenance of chemical protective clothing is given in BS 7184:1989.

**Table 13.12 Glove material resistance rating (courtesy James North & Sons Ltd)**

| <i>Chemical</i>                 | <i>Glove material</i> |                 |                |                   |                       |
|---------------------------------|-----------------------|-----------------|----------------|-------------------|-----------------------|
|                                 | <i>Natural rubber</i> | <i>Neoprene</i> | <i>Nitrile</i> | <i>Normal PVC</i> | <i>High grade PVC</i> |
| <b>Organic acids</b>            |                       |                 |                |                   |                       |
| Acetic acid                     | E                     | E               | E              | E                 | E                     |
| Citric acid                     | E                     | E               | E              | E                 | E                     |
| Formic acid                     | E                     | E               | E              | E                 | E                     |
| Lactic acid                     | E                     | E               | E              | E                 | E                     |
| Lauric acid                     | E                     | E               | E              | E                 | E                     |
| Maleic acid                     | E                     | E               | E              | E                 | E                     |
| Oleic acid                      | E                     | E               | E              | E                 | E                     |
| Oxalic acid                     | E                     | E               | E              | E                 | E                     |
| Palmitic acid                   | E                     | E               | E              | E                 | E                     |
| Phenol                          | E                     | E               | G              | E                 | E                     |
| Propionic acid                  | E                     | E               | E              | E                 | E                     |
| Stearic acid                    | E                     | E               | E              | E                 | E                     |
| Tannic acid                     | E                     | E               | E              | E                 | E                     |
| <b>Inorganic acids</b>          |                       |                 |                |                   |                       |
| Arsenic acid                    | G                     | G               | G              | E                 | E                     |
| Carbonic acid                   | G                     | G               | G              | E                 | E                     |
| Chromic acid (up to 50%)        | G                     | F               | F              | E <sup>(1)</sup>  | G                     |
| Fluorosilicic acid              | G                     | G               | G              | E                 | G                     |
| Hydrochloric acid (up to 40%)   | G                     | G               | G              | E                 | G                     |
| Hydrofluoric acid               | G                     | G               | G              | E <sup>(1)</sup>  | G                     |
| Hydrogen sulphide (acid)        | F                     | F               | G              | E                 | E                     |
| Hydrogen peroxide               | G                     | G               | G              | E                 | E                     |
| Nitric acid (up to 50%)         | NR                    | NR              | NR             | G <sup>(1)</sup>  | F <sup>(1)</sup>      |
| Perchloric acid                 | F                     | G               | F              | E <sup>(1)</sup>  | G                     |
| Phosphoric acid                 | G                     | G               | G              | E                 | G                     |
| Sulphuric acid (up to 50%)      | G                     | G               | F              | E <sup>(1)</sup>  | G                     |
| Sulphurous acid                 | G                     | G               | G              | E                 | E                     |
| <b>Saturated salt solutions</b> |                       |                 |                |                   |                       |
| Ammonium acetate                | E                     | E               | E              | E                 | E                     |
| Ammonium carbonate              | E                     | E               | E              | E                 | E                     |
| Ammonium lactate                | E                     | E               | E              | E                 | E                     |
| Ammonium nitrate                | E                     | E               | E              | E                 | E                     |
| Ammonium nitrite                | E                     | E               | E              | E                 | E                     |
| Ammonium phosphate              | E                     | E               | E              | E                 | E                     |
| Calcium hypochlorite            | NR                    | G               | G              | E                 | E                     |
| Ferric chloride                 | E                     | E               | E              | E                 | E                     |
| Magnesium chloride              | E                     | E               | E              | E                 | E                     |
| Mercuric chloride               | G                     | G               | G              | E                 | E                     |
| Potassium chromate              | E                     | E               | E              | E                 | E                     |
| Potassium cyanide               | E                     | E               | E              | E                 | E                     |
| Potassium dichromate            | E                     | E               | E              | E                 | E                     |
| Potassium halides               | E                     | E               | E              | E                 | E                     |
| Potassium permanganate          | E                     | E               | E              | E                 | E                     |
| Sodium carbonate                | E                     | E               | E              | E                 | E                     |
| Sodium chloride                 | E                     | E               | E              | E                 | E                     |
| Sodium hypochlorite             | NR                    | F               | F              | E                 | E                     |
| Sodium nitrate                  | E                     | E               | E              | E                 | E                     |
| Solutions of copper salts       | G                     | G               | G              | E                 | E                     |
| Stannous chloride               | E                     | E               | E              | E                 | E                     |
| Zinc chloride                   | E                     | E               | E              | E                 | E                     |
| <b>Alkalis</b>                  |                       |                 |                |                   |                       |
| Ammonium hydroxide              | E                     | E               | E              | E                 | E                     |
| Calcium hydroxide               | E                     | E               | E              | E                 | E                     |
| Potassium hydroxide             | E                     | G               | G              | E                 | E                     |

Table 13.12 Cont'd

| Chemical                                      | Natural rubber | Glove material |         |            |                  |
|-----------------------------------------------|----------------|----------------|---------|------------|------------------|
|                                               |                | Neoprene       | Nitrile | Normal PVC | High grade PVC   |
| Sodium hydroxide                              | E              | G              | G       | E          | E                |
| <b>Aliphatic hydrocarbons</b>                 |                |                |         |            |                  |
| Hydraulic oil                                 | F              | G              | F       | G          | E                |
| Paraffins                                     | F              | G              | E       | G          | E                |
| Petroleum ether                               | F              | G              | E       | F          | G                |
| Pine oil                                      | G              | G              | E       | G          | E                |
| <b>Aromatic hydrocarbons<sup>(2)</sup></b>    |                |                |         |            |                  |
| Benzene                                       | NR             | F              | G       | F          | G                |
| Naphtha                                       | NR             | F              | F       | F          | G                |
| Naphthalene                                   | G              | G              | E       | G          | E                |
| Toluene                                       | NR             | F              | G       | F          | G                |
| Turpentine                                    | F              | G              | R       | F          | G                |
| Xylene                                        | NR             | F              | G       | F          | G <sup>(1)</sup> |
| <b>Halogenated hydrocarbons<sup>(2)</sup></b> |                |                |         |            |                  |
| Benzyl chloride                               | F              | F              | G       | F          | G                |
| Carbon tetrachloride                          | F              | F              | G       | F          | G                |
| Chloroform                                    | F              | F              | G       | F          | G                |
| Ethylene dichloride                           | F              | F              | G       | F          | G                |
| Methylene chloride                            | F              | F              | G       | F          | G                |
| Perchloroethylene                             | F              | F              | G       | F          | G                |
| Trichloroethylene                             | F              | F              | G       | F          | G                |
| <b>Esters</b>                                 |                |                |         |            |                  |
| Amyl acetate                                  | F              | G              | G       | F          | G                |
| Butyl acetate                                 | F              | G              | G       | F          | G                |
| Ethyl acetate                                 | F              | G              | G       | F          | G                |
| Ethyl butyrate                                | F              | G              | G       | F          | G                |
| Methyl butyrate                               | F              | G              | G       | F          | G                |
| <b>Ethers</b>                                 |                |                |         |            |                  |
| Diethyl ether                                 | F              | G              | E       | F          | G                |
| <b>Aldehydes</b>                              |                |                |         |            |                  |
| Acetaldehyde                                  | G              | E              | E       | E          | E                |
| Benzaldehyde                                  | F              | F              | E       | G          | E                |
| Formaldehyde                                  | G              | E              | E       | E          | E                |
| <b>Ketones</b>                                |                |                |         |            |                  |
| Acetone                                       | G              | G              | G       | F          | G                |
| Diethyl ketone                                | G              | G              | G       | F          | G                |
| Methyl ethyl ketone                           | G              | G              | G       | F          | G                |
| <b>Alcohols</b>                               |                |                |         |            |                  |
| Amyl alcohol                                  | E              | E              | E       | E          | E                |
| Butyl alcohol                                 | E              | E              | E       | E          | E                |
| Ethyl alcohol                                 | E              | E              | E       | E          | E                |
| Ethylene glycol                               | G              | G              | E       | E          | E                |
| Glycerol                                      | G              | G              | E       | E          | E                |
| Isopropyl alcohol                             | E              | E              | E       | E          | E                |
| Methyl alcohol                                | E              | E              | E       | E          | E                |
| <b>Amines</b>                                 |                |                |         |            |                  |
| Aniline                                       | F              | G              | E       | E          | E                |
| Butylamine                                    | G              | G              | E       | E          | E                |
| Ethylamine                                    | G              | G              | E       | E          | E                |
| Ethylaniline                                  | F              | G              | E       | E          | E                |
| Methylamine                                   | G              | G              | E       | E          | E                |
| Methylaniline                                 | F              | G              | E       | E          | E                |
| Triethanolamine                               | G              | E              | E       | E          | E                |

Table 13.12 Cont'd

| Chemical                   | Glove material |          |         |            |                |
|----------------------------|----------------|----------|---------|------------|----------------|
|                            | Natural rubber | Neoprene | Nitrile | Normal PVC | High grade PVC |
| <b>Miscellaneous</b>       |                |          |         |            |                |
| Animal fats                | F              | G        | G       | G          | E              |
| Bleaches                   | NR             | G        | G       | G          | E              |
| Carbon disulphide          | NR             | F        | G       | F          | G              |
| Degreasing solution        | F              | F        | G       | F          | G              |
| Diesel fuel                | NR             | F        | G       | F          | E              |
| Hydraulic fluids           | F              | G        | G       | G          | E              |
| Mineral oils               | F              | G        | E       | G          | E              |
| Ozone                      | F              | E        | G       | E          | E              |
| Paint and varnish removers | F              | G        | G       | F          | G              |
| Petrol                     | NR             | G        | G       | F          | G              |
| Photographic solutions     | G              | E        | E       | G          | E              |
| Plasticizers               | F              | G        | E       | G          | E              |
| Printing inks              | G              | G        | E       | G          | E              |
| Refrigerant solutions      | G              | G        | E       | F          | G              |
| Resin oil                  | F              | G        | G       | G          | E              |
| Vegetable oils             | F              | G        | G       | G          | E              |
| Weed killers               | G              | E        | E       | G          | E              |
| White spirit               | F              | G        | G       | F          | G              |
| Wood preservatives         | NR             | G        | G       | F          | G              |

E Excellent

F Fair

G Good

NR Not recommended

<sup>(1)</sup>Resistance not absolute, but the best available.<sup>(2)</sup>Aromatic and halogenated hydrocarbons will attack all types of natural and synthetic gloves. Should swelling occur, switch to another pair, allowing the swollen gloves to dry and return to normal.

Impervious clothing is essential when handling corrosive chemicals, liquids liable to cause dermatitis, or chemicals toxic by skin absorption.

All protective clothing should be maintained in a sound condition, cleaned/washed/replaced regularly as appropriate, and be stored apart from everyday clothing. With toxic chemicals a double locker system is advisable. With highly toxic substances, e.g. lead compounds or asbestos-based substances, separate storage of personal clothing and protective clothing is specifically required.

### ***Protective footwear***

Protective footwear includes shoes, boots with steel toecaps, full boots, e.g. Wellingtons. The choice of material determines durability, acid resistance, oil resistance, heat resistance, non-slip characteristics, impact resistance etc.

### ***Washing facilities***

Wherever chemicals are handled, adequate washing facilities are required conveniently situated with respect to the workplace. These comprise wash-basins or troughs with a constant supply of hot and cold or warm water; soap or liquid hand cleanser; clean towels or hot-air driers or disposable paper towels. Typical minimum standards are:

Normal work

Handling toxic or irritant chemicals

One wash-basin per 10 workers

One wash-basin per 5 workers

**Table 13.13 Properties of protective clothing materials**

| <i>Material</i>                     | <i>Advantages</i>                                                                                                                                             | <i>Disadvantages</i>                                                                                                               |                                                                                                         |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Cotton                              | Lightweight, reasonably hard-wearing, no static generation<br>Resists penetration of direct splashes of corrosive<br>Unaffected by oils                       | Liable to shrinkage unless treated<br>More flammable than wool<br>Vulnerable to hot splashes                                       | Suitable for under-gloves                                                                               |
| Wool                                | Resists rapid penetration of direct splashes (more effective than cotton)<br>Resists penetration of dust<br>High absorption and porosity absorbs perspiration | Not resistant to hot splashes<br>Takes up water and dirt<br>Difficult to wash                                                      |                                                                                                         |
| Artificial fibres (nylon, Terylene) | Hardwearing<br>Terylene has good acid resistance                                                                                                              | Not resistant to hot splashes<br>High initial cost<br>Can allow dust to pass through<br>Static electricity can cause rapid soiling | Ceramic coating of fibres can render dust-proof                                                         |
| PVC                                 | Impervious<br>Non-flammable<br>Chemically and biologically resistant<br>Abrasion resistant                                                                    | Not resistant to hot splashes<br>Causes sweating unless well ventilated                                                            | Used alone or impregnated on fabric<br>For gloves armlets, hats, bibs, spats, suits                     |
| Paper                               | Hygienic (disposable)<br>Fairly resistant to chemicals if treated with polythene film                                                                         | Liable to wetting if not treated with polythene film<br>No strength<br>Flammable<br>Not resistant to hot splashes                  | Possibly used for disposable underwear or for clothing for visitors<br>Used under headgear (disposable) |
| Polythene                           | Hygienic<br>May be disposable<br>Impervious                                                                                                                   | Low abrasion resistance<br>Not resistant to hot splashes<br>Low melting point could cause adhesion to skin                         | Suitable for disposable gloves or headgear                                                              |

In some circumstances, where clothing has to be changed, bathing facilities, e.g. showers, are required. The provision of suitable and sufficient washing facilities and showers, if required by the nature of the work, at readily accessible places is required in the UK under Reg. 21 of the Workplace (Health, Safety and Welfare) Regulations 1992. Specific needs are also covered in other legislation, e.g. the Control of Lead at Work Regulations, and the Control of Asbestos at Work Regulations 1987 (as amended 1998).

### ***Facilities for rest and food***

Rest facilities should be provided in readily accessible places. To avoid contamination of food, or accidental ingestion of chemicals, these should include facilities to eat meals in a separate location.

## **Medical screening**

The medical background of workers must be considered for work involving certain chemicals, e.g. radioactive substances, sensitizers. (Refer to Chapter 5.)



## **Monitoring standards**

Management must institute procedures to assess levels of compliance with agreed standards for safety. Techniques include environmental and/or biological monitoring, health surveillance, safety audits, safety inspections, and procedures for accident reporting, investigation and analysis. Communication is essential, e.g. by provision of information (on specific chemicals, processes, etc.), safety meetings, notices, safety bulletins etc.

## **Training**

Education, training and supervision are essential for the safe handling of chemicals. Training requirements vary according to position within the organization, and hence responsibility.

Topics should embrace a knowledge of the hazards and precautions, including the use and maintenance of protective devices including personal protection, under both normal and abnormal operating conditions including emergencies.

# Marketing

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Chemicals vary from commodity substances in bulk to household cleaning products in small packages. Mixtures of chemicals, such as formulated products, are usually termed 'preparations' which constitute 95% of commercially-available dangerous chemicals. Manufacturers, suppliers and importers of all chemicals have a legal obligation to ensure that their products are fit for use, properly packed, labelled and transported, and to provide the user with information on the hazards and precautions to ensure they can be used safely and without harm to the environment. (See Table 14.1 for UK legislation.) The hazards of dangerous substances, as opposed to dangerous preparations, must also appear in advertisements for those chemicals.

Important aspects of classification labelling and packaging chemicals are regulated in the UK by the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 ('CHIP'). These are applicable to any substance dangerous for supply excluding specific categories, e.g. cosmetic products, controlled drugs, foods, medicines and medical products, munitions, wastes, radioactive substances.

## Classification

If a chemical is hazardous it is first classified into an appropriate category of danger to assist in the provision of the correct information and packaging.

This can be done by:

- use of the classification given to it by the supplier. (A check is necessary that the classification is accurate and also that processing has not invalidated it);
- use of an Approved Supply List from the UK Health and Safety Executive which covers most chemicals but not mixtures; or
- classification by reference to relevant information.

A list of danger categories is given in Table 14.2. Note that chemicals may possess several hazards, e.g. nitric acid is classed as both an oxidizer and a corrosive. If a chemical is not in one of these categories it is not generally considered to be dangerous. If the hazards of a new chemical have not been established it should be labelled 'Caution – substance not yet fully tested'. Mixtures can be classified either from results from tests on the preparation, or by calculation to predict the health effects of the product based on the properties of individual components and their concentration in the mixture. Preparations need to be classified for both physico-chemical and health effects but, to date, not for environmental effects.

Under CHIP there is a requirement for suppliers to exercise all due diligence in classifying a

**Table 14.1 Legislation affecting the classification, packaging, labelling and carriage of dangerous substances in Great Britain (including their movement in harbours and harbour areas)**

|                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>The Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 as amended</b>                                                  | Control the classification, provision of labels and safety data sheets, and safe packaging of chemicals by supplier.                                                                                                                                                                                                                                                                                                                                                                         |
| <b>The Carriage of Dangerous Goods by Road Regulations 1996</b>                                                                                 | Covers the mode of dispatch of dangerous goods by road including bulk and tanker transport; suitability of containers and vehicles; examination and testing; information requirements; loading and unloading; procedures for emergencies and parking; exemptions.                                                                                                                                                                                                                            |
| <b>The Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996</b> | Governs the classification of dangerous goods; consignment in packages and their markings/labelling; the design, manufacture, modification and repair of transportable pressure receptacles and their approval and certification, marking and filling; the role of approved persons and the need for records.                                                                                                                                                                                |
| <b>The Carriage of Dangerous Goods by Road (Driver Training) Regulations 1996</b>                                                               | Addresses the instruction, training and certification of drivers of road vehicles used for the carriage of dangerous goods.                                                                                                                                                                                                                                                                                                                                                                  |
| <b>The Carriage of Explosives by Road Regulations 1996</b>                                                                                      | Scope includes mode of transport in both passenger vehicles and bulk carriage; suitability of vehicle and container; approval; quantity limits; mixed loads; information and documentation; safety and security during carriage; equipment; precautions against fire and explosion and in the event of accidents and emergencies; age limits for those engaged in the carriage.                                                                                                              |
| <b>The Carriage of Dangerous Goods by Rail Regulations 1996</b>                                                                                 | Governs the transport of dangerous goods by rail in small containers, large containers, tanks and wagons. Covers classification of dangerous goods; suitability, examination and testing of container; information including labelling. Also included is training and instruction; loading and unloading; marshalling; prohibition of overfilling, mixed loads and temperature-controlled substances; security and emergency procedures and special requirements for carriage of explosives. |
| <b>The Packaging, Labelling and Carriage of Radioactive Materials by Rail Regulations 1996</b>                                                  | Covers package design, approval, test procedures, notification of consignment, information requirements (for package and transport container).                                                                                                                                                                                                                                                                                                                                               |
| <b>Radioactive Material (Road Transport) (Great Britain) Regulations 1996</b>                                                                   | Includes radiation limits, prior approval, QA programmes, testing procedures, information/documentation requirements, and marking/labelling/placarding.                                                                                                                                                                                                                                                                                                                                      |
| <b>The Health and Safety at Work etc. Act 1974 (Application to Environmentally Hazardous Substances) Regulations 1996 as amended</b>            | Extends the scope of Health and Safety at Work etc. Act 1974 to include environmentally-hazardous substances including transportation of such dangerous goods and the control of volatile organic carbon emissions from storage and distribution of petrol.                                                                                                                                                                                                                                  |
| <b>The Ionizing Radiations Regulations 1999</b>                                                                                                 | Apply to all work activities with radioactive materials, including transport. The main provisions relevant to transport are those relating to driver training and the need, under some circumstances, to prepare contingency plans for emergencies and enforced stoppages.                                                                                                                                                                                                                   |
| <b>The Dangerous Substances in Harbour Areas Regulations 1987 ('DSHA')</b>                                                                      | Control the carriage, loading, unloading and storage of all classes of dangerous substances, including explosives, in all harbours and harbour areas in Great Britain. Movement of dangerous substances by road, rail and sea is covered.                                                                                                                                                                                                                                                    |

Table 14.1 Cont'd

|                                                                                 |                                                                                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>The Classification and Labelling of Explosives Regulations 1983 ('CLER')</b> | Require that explosives shall not be transported unless they have been classified by the classifying authority (i.e. the HSE, and the MOD for military explosives, in the UK) (except for journeys made specifically for classification and then only under certain conditions). |
|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

substance. Checks which may be required if reliance is placed on classification by a manufacturer are:

- reference to the Approved Supply List;
- use of experience about the reliability and experience of the supplier;
- use of common sense and experience;
- comparison with similar substances or preparations;
- comparison with any classification for carriage;
- enquiries with the supplier or other competent persons;
- checking with information in reference textbooks.

## Packaging

A hazardous chemical must be supplied/conveyed in a package (drum, keg, cylinder, bottle, etc.) suitable for the purpose. In particular:

The receptacle and any associated packaging must be designed, constructed, maintained and closed so as to prevent the escape of any of the contents of the receptacle when subjected to the stresses and strains of normal handling. A suitable safety device (e.g. pressure relief valve) may be fitted.

The receptacle and any associated packagings (in so far as they are likely to come into contact with the dangerous substance) must be made of materials (a) which are not liable to be adversely affected by the substance, and (b) which are not liable to react with the substance to form any other dangerous substance.

Where the receptacle is fitted with a replaceable closure, the closure must be designed so that the receptacle can be repeatedly reclosed without the contents escaping.

The packaging of certain dangerous chemicals (e.g. those labelled 'toxic', 'very toxic' or 'corrosive' must be fitted with child-resistant closures, or tactile danger warnings (for the blind) if sold to the public.

Suppliers should perform a hazard analysis on each product. For example, aerosols can pose fire, explosion or inhalation risk. Basic precautions with an aerosol dispenser are:

Assume that the aerosol contains a liquid of flammability equivalent to that of petrol and treat it as such.

Do not use an aerosol spray when smoking, or near any other source of ignition, e.g. an electric fire, hot-plate, open-flame heater or boiler etc.

Do not throw used aerosol dispensers onto bonfires.

Do not let young children have access to aerosol dispensers, full or empty.

**Table 14.2 Indication of dangers with chemical products**

|                  | <i>Category of danger</i>                                     | <i>Indication of danger</i>   | <i>Symbol</i>                                                                         | <i>Symbol letter</i> |
|------------------|---------------------------------------------------------------|-------------------------------|---------------------------------------------------------------------------------------|----------------------|
| Physico-chemical | Explosive                                                     | Explosive                     |    | E                    |
|                  | Oxidizing                                                     | Oxidizing                     |    | O                    |
|                  | Extremely flammable                                           | Extremely flammable           |    | F+                   |
|                  | Highly flammable                                              | Highly flammable              |    | F                    |
|                  | Flammable                                                     | Flammable                     |    | —                    |
| Health           | Very toxic                                                    | Very toxic                    |    | T+                   |
|                  | Toxic                                                         | Toxic                         |    | T                    |
|                  | Harmful                                                       | Harmful                       |    | Xn                   |
|                  | Corrosive                                                     | Corrosive                     |    | C                    |
|                  | Irritant                                                      | Irritant                      |    | Xi                   |
|                  | Sensitizing                                                   | Harmful                       |   | Xn                   |
|                  |                                                               | Irritant                      |  | Xi                   |
|                  | Carcinogenic<br>Categories 1 and 2<br>Category 3              | Toxic                         |  | T                    |
|                  |                                                               | Harmful                       |  | Xn                   |
|                  | Mutagenic<br>Categories 1 and 2<br>Category 3                 | Toxic                         |  | T                    |
|                  |                                                               | Harmful                       |  | Xn                   |
|                  | Toxic for<br>reproduction<br>Categories 1 and 2<br>Category 3 | Toxic                         |  | T                    |
|                  |                                                               | Harmful                       |  | Xn                   |
| Environmental    | Dangerous for the environment                                 | Dangerous for the environment |  | N                    |

It is the responsibility of the supplier to draw these precautions to the attention of the user in the best way practicable.

## Labelling

If a dangerous chemical is supplied in a package then the package must be labelled. Clearly this is not practical if the chemical is delivered in bulk or via a pipeline.

The elements of a label are:

Full name and address and phone number of supplier.

Chemical name or, if a preparation, the trade name.

Indication of danger and associated symbol.

Risk and safety phrases.

Requirements for labelling of containers for supply may differ from those for conveyance. Key features of a supply label are to identify the substance (the chemical name in most cases) and any hazards and safety precautions. Supply labels are black on yellow/orange. In Europe the classification, packaging and labelling of dangerous substances is covered by Directive 67/548/EEC as amended. This requires labels to identify appropriate risk and safety phrases (Tables 14.3 and 14.4) depending upon product properties. A substance is considered dangerous if in Part 1A of an approved list or if it exhibits hazardous properties as defined in Schedule 1 for supply, or Schedule 2 for conveyance as shown in Tables 14.5 and 14.6. Substances not tested should be labelled 'Caution – substance not yet fully tested'. Criteria for risk phrases are provided, e.g. as in Table 14.7 for toxic compounds.

Explosive chemicals tend to be governed by separate legislation, e.g., in the UK, The Classification and Labelling of Explosives Regulations 1983. These require the HSE to classify any explosive before it may be supplied. Under the scheme, explosives are labelled according to a classification based on hazard division (Table 14.8), and on compatibility (Table 14.9), which takes into account their sensitivity, explosivity and chemical nature. Labels are diamond shaped: the top half is reserved for the pictograph and division number, the bottom half shows the hazard code and the classification number. Figure 14.1 shows the label for Class 1, Division 1.1, 1.2 or 1.3 explosive.



**Figure 14.1** Example of label for explosive (Division 1.1, 1.2 or 1.3)

**Table 14.3 'Risk' phrases from the Approved List**

1. Explosive when dry
2. Risk of explosion by shock, friction, fire or other sources of ignition
3. Extreme risk of explosion by shock, friction, fire or other sources of ignition
4. Forms very sensitive explosive metallic compounds
5. Heating may cause an explosion
6. Explosive with or without contact with air
7. May cause fire
8. Contact with combustible material may cause fire
9. Explosive when mixed with combustible material
10. Flammable
11. Highly flammable
12. Extremely flammable
13. Extremely flammable liquefied gas
14. Reacts violently with water
15. Contact with water liberates extremely flammable gases
16. Explosive when mixed with oxidizing substances
17. Spontaneously flammable in air
18. In use, may form flammable/explosive vapour–air mixture
19. May form explosive peroxides
20. Harmful by inhalation
21. Harmful in contact with skin
22. Harmful if swallowed
23. Toxic by inhalation
24. Toxic in contact with skin
25. Toxic if swallowed
26. Very toxic by inhalation
27. Very toxic in contact with skin
28. Very toxic if swallowed
29. Contact with water liberates toxic gas
30. Can become highly flammable in use
31. Contact with acids liberates toxic gas
32. Contact with acids liberates very toxic gas
33. Danger of cumulative effects
34. Causes burns
35. Causes severe burns
36. Irritating to eyes
37. Irritating to respiratory system
38. Irritating to skin
39. Danger of very serious irreversible effects
40. Possible risk of irreversible effects
41. Risk of serious damage to eyes
42. May cause sensitization by inhalation
43. May cause sensitization by skin contact
44. Risk of explosion if heated under confinement
45. May cause cancer
46. May cause heritable genetic damage
47. May cause birth defects
48. Danger of serious damage to health by prolonged exposure
49. May cause cancer by inhalation
50. Very toxic to aquatic organisms
51. Toxic to aquatic organisms
52. Harmful to aquatic organisms
53. May cause long-term adverse effects in the aquatic environment
54. Toxic to flora
55. Toxic to fauna
56. Toxic to soil organisms
57. Toxic to bees
58. May cause long-term adverse effects in the environment
59. Dangerous for the ozone layer

Table 14.3 Cont'd

60. May impair fertility
61. May cause harm to the unborn child
62. Possible risk of impaired fertility
63. Possible risk of harm to the unborn child
64. May cause harm to breastfed babies
65. Harmful: may cause lung damage if swallowed
66. Repeat exposure may cause skin dryness or cracking
67. Vapours may cause drowsiness and dizziness

**Examples of combination of particular risks**

- |             |                                                                                                                            |
|-------------|----------------------------------------------------------------------------------------------------------------------------|
| 14/15       | Reacts violently with water, liberating extremely flammable gases                                                          |
| 15/29       | Contact with water liberates toxic, extremely flammable gas                                                                |
| 20/21       | Harmful by inhalation and in contact with skin                                                                             |
| 20/21/22    | Harmful by inhalation, in contact with skin and if swallowed                                                               |
| 20/22       | Harmful by inhalation and if swallowed                                                                                     |
| 21/22       | Harmful in contact with skin and if swallowed                                                                              |
| 23/24       | Toxic by inhalation and in contact with skin                                                                               |
| 23/24/25    | Toxic by inhalation, in contact with skin, and if swallowed                                                                |
| 23/25       | Toxic by inhalation and if swallowed                                                                                       |
| 24/25       | Toxic in contact with skin and if swallowed                                                                                |
| 26/27       | Very toxic by inhalation and in contact with skin                                                                          |
| 26/27/28    | Very toxic by inhalation, in contact with skin and if swallowed                                                            |
| 26/28       | Very toxic by inhalation and if swallowed                                                                                  |
| 27/28       | Very toxic in contact with skin and if swallowed                                                                           |
| 36/37       | Irritating to eyes and respiratory system                                                                                  |
| 36/37/38    | Irritating to eyes, respiratory system and skin                                                                            |
| 36/38       | Irritating to eyes and skin                                                                                                |
| 37/38       | Irritating to respiratory system and skin                                                                                  |
| 39/23       | Toxic: danger of very serious irreversible effects through inhalation                                                      |
| 39/23/24    | Toxic: danger of very serious irreversible effects through inhalation and in contact with skin                             |
| 39/23/24/25 | Toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed               |
| 39/23/25    | Toxic: danger of very serious irreversible effects through inhalation, and if swallowed                                    |
| 39/24       | Toxic: danger of very serious irreversible effects in contact with skin                                                    |
| 39/24/25    | Toxic: danger of very serious irreversible effects in contact with skin and if swallowed                                   |
| 39/25       | Toxic: danger of very serious irreversible effects if swallowed                                                            |
| 39/26       | Very toxic: danger of very serious irreversible effects through inhalation                                                 |
| 39/26/27    | Very toxic: danger of very serious irreversible effects through inhalation and in contact with skin                        |
| 39/26/27/28 | Very toxic: danger of very serious irreversible effects through inhalation, in contact with skin and if swallowed          |
| 39/26/28    | Very toxic: danger of very serious irreversible effects through inhalation and if swallowed                                |
| 39/27       | Very toxic: danger of very serious irreversible effects in contact with skin                                               |
| 39/27/28    | Very toxic: danger of very serious irreversible effects in contact with skin and if swallowed                              |
| 39/28       | Very toxic: danger of very serious irreversible effects if swallowed                                                       |
| 40/20       | Harmful: possible risk of irreversible effects through inhalation                                                          |
| 40/20/21    | Harmful: possible risk of irreversible effects through inhalation and in contact with skin                                 |
| 40/20/21/22 | Harmful: possible risk of irreversible effects through inhalation in contact with skin and if swallowed                    |
| 40/20/22    | Harmful: possible risk of irreversible effects through inhalation and if swallowed                                         |
| 40/22       | Harmful: possible risk of irreversible effects if swallowed                                                                |
| 40/21       | Harmful: possible risk of irreversible effects in contact with skin                                                        |
| 40/21/22    | Harmful: possible risk of irreversible effects in contact with skin and if swallowed                                       |
| 42/43       | May cause sensitization by inhalation and skin contact                                                                     |
| 48/20       | Harmful: danger of serious damage to health by prolonged exposure through inhalation                                       |
| 48/20/21    | Harmful: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin              |
| 48/20/21/22 | Harmful: danger of serious damage to health by prolonged exposure through inhalation in contact with skin and if swallowed |
| 48/20/22    | Harmful: danger of serious damage to health by prolonged exposure through inhalation and if swallowed                      |
| 48/21       | Harmful: danger of serious damage to health by prolonged exposure in contact with skin                                     |
| 48/21/22    | Harmful: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed                    |
| 48/22       | Harmful: danger of serious damage to health by prolonged exposure if swallowed                                             |
| 48/23       | Toxic: danger of serious damage to health by prolonged exposure through inhalation                                         |



**Table 14.3 Cont'd**

|             |                                                                                                                           |
|-------------|---------------------------------------------------------------------------------------------------------------------------|
| 48/23/24    | Toxic: danger of serious damage to health by prolonged exposure through inhalation and in contact with skin               |
| 48/23/24/25 | Toxic: danger of serious damage to health by prolonged exposure through inhalation, in contact with skin and if swallowed |
| 48/23/25    | Toxic: danger of serious damage to health by prolonged exposure through inhalation and if swallowed                       |
| 48/24       | Toxic: danger of serious damage to health by prolonged exposure in contact with skin                                      |
| 48/24/25    | Toxic: danger of serious damage to health by prolonged exposure in contact with skin and if swallowed                     |
| 48/25       | Toxic: danger of serious damage to health by prolonged exposure if swallowed                                              |
| 50/53       | Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment                           |
| 51/53       | Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment                                |
| 52/53       | Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment                              |

**Table 14.4 'Safety' phrases from the Approved List**

1. Keep locked up
2. Keep out of reach of children
3. Keep in a cool place
4. Keep away from living quarters
5. Keep contents under . . . (appropriate liquid to be specified by the manufacturer)
6. Keep under . . . (inert gas to be specified by the manufacturer)
7. Keep container tightly closed
8. Keep container dry
9. Keep container in a well-ventilated place
12. Do not keep the container sealed
13. Keep away from food, drink and animal feeding stuffs
14. Keep away from . . . (incompatible materials to be indicated by the manufacturer)
15. Keep away from heat
16. Keep away from sources of ignition – No Smoking
17. Keep away from combustible material
18. Handle and open container with care
20. When using do not eat or drink
21. When using do not smoke
22. Do not breathe dust
23. Do not breathe gas/fumes/vapour/spray (appropriate wording to be specified by manufacturer)
24. Avoid contact with skin
25. Avoid contact with eyes
26. In case of contact with eyes, rinse immediately with plenty of water and seek medical advice
27. Take off immediately all contaminated clothing
28. After contact with skin, wash immediately with plenty of . . . (to be specified by the manufacturer)
29. Do not empty into drains
30. Never add water to this product
33. Take precautionary measures against static discharges
35. This material and its container must be disposed of in a safe way
36. Wear suitable protective clothing
37. Wear suitable gloves
38. In case of insufficient ventilation, wear suitable respiratory equipment
39. Wear eye/face protection
40. To clean the floor and all objects contaminated by this material use . . . (to be specified by the manufacturer)
41. In case of fire and/or explosion do not breathe fumes
42. During fumigation/spraying wear suitable respiratory equipment (appropriate wording to be specified by the manufacturers)
43. In case of fire, use . . . (indicate in the space the precise type of fire-fighting equipment. If water increases the risk, add – Never use water)
45. In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible)
46. If swallowed seek medical advice immediately and show this container or label
47. Keep at temperature not exceeding . . . °C (to be specified by the manufacturer)
48. Keep wetted with . . . (appropriate material to be specified by the manufacturer)
49. Keep only in the original container
50. Do not mix with . . . (to be specified by the manufacturer)
51. Use only in well-ventilated areas

Table 14.4 Cont'd

- 
- 52. Not recommended for interior use on large surface areas
  - 53. Avoid exposure – obtain special instructions before use
  - 56. Dispose of this material and its container to hazardous or special waste collection point
  - 57. Use appropriate containment to avoid environmental contamination
  - 59. Refer to manufacturer/supplier for information on recovery/recycling
  - 60. This material and/or its container must be disposed of as hazardous waste
  - 61. Avoid release to the environment. Refer to special instructions/safety data sheet
  - 62. If swallowed, do not induce vomiting; seek medical advice immediately and show this container or label
  - 63. In case of accident by inhalation: remove casualty to fresh air and keep at rest
  - 64. If swallowed, rinse mouth with water (only if the person is conscious)
- 

*Examples of combination of safety precautions*

|           |                                                                                                                                        |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------|
| 1/2       | Keep locked up and out of the reach of children                                                                                        |
| 3/9/14    | Keep in a cool well-ventilated place away from [incompatible materials to be indicated by manufacturer]                                |
| 3/9/14/49 | Keep only in the original container in a cool well-ventilated place away from [incompatible materials to be indicated by manufacturer] |
| 3/9/49    | Keep only in the original container in a cool well-ventilated place                                                                    |
| 3/14      | Keep in a cool place away from [incompatible materials to be indicated by the manufacturer]                                            |
| 7/8       | Keep container tightly closed and dry                                                                                                  |
| 7/9       | Keep container tightly closed and in a well-ventilated place                                                                           |
| 7/47      | Keep container tightly closed and at a temperature not exceeding [ ]°C [to be specified by manufacturer]                               |
| 20/21     | When using do not eat, drink or smoke                                                                                                  |
| 24/25     | Avoid contact with skin and eyes                                                                                                       |
| 29/56     | Do not empty into drains, dispose of this material and its container to hazardous or special waste collection point                    |
| 36/37     | Wear suitable protective clothing and gloves                                                                                           |
| 37/38/39  | Wear suitable protective clothing, gloves and eye/face protection                                                                      |
| 36/39     | Wear suitable protective clothing and eye/face protection                                                                              |
| 37/39     | Wear suitable gloves and eye/face protection                                                                                           |
| 47/49     | Keep only in the original container at temperature not exceeding [ ]°C [to be specified by manufacturer]                               |

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## Information

Suppliers must also provide the customer with more detailed information on the hazards and safety precautions of their products. If the chemicals are to be used in connection with work this is usually in a Material Safety Data Sheet. Relevant information from Table 1.10 should be included and at least cover that listed in Table 14.10.

The information must be provided under the headings shown in Table 14.11 and enable the user to determine the precautions required when using the chemical.

Where necessary the manufacturer must carry out, or arrange for, safety testing. Many countries operate mandatory premanufacturing and premarketing notification schemes of which safety testing is the cornerstone. Within the European Community under Directive 67/548/EEC and its sixth amendment 79/831/EEC, Competent Authorities must be notified before new substances are supplied in the marketplace. In the UK this Directive is enacted by the Notification of New Substances Regulations 1993 (NONS). Exempt are:

Substances listed on the European Inventory of Existing Chemical Substances (EINECS).  
Medicinal products.

**Table 14.5 Classification of and symbols for substances dangerous for supply (Schedule 1 Part I)**

| <i>Characteristic properties of the substance</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <i>Classification and indication of general nature of risk</i> | <i>Symbol</i>                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------------|
| A substance which may explode under the effect of flame or which is more sensitive to shocks or friction than dinitrobenzene.                                                                                                                                                                                                                                                                                                                                                                                                                 | Explosive                                                      |    |
| A substance which gives rise to highly exothermic reaction when in contact with other substances, particularly flammable substances.                                                                                                                                                                                                                                                                                                                                                                                                          | Oxidizing                                                      |    |
| A liquid having a flash point <0 C and a boiling point ≤35 C.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Extremely flammable <sup>(1)</sup>                             |    |
| A substance which<br>(a) may become hot and finally catch fire in contact with air at ambient temperature without any application of energy;<br>(b) is a solid and may readily catch fire after brief contact with a source of ignition and which continues to burn or to be consumed after removal of the source of ignition;<br>(c) is gaseous and flammable in air at normal pressure;<br>(d) in contact with water or damp air, evolves highly flammable gases in dangerous quantities; or<br>(e) is a liquid having a flash point <21 C. | Highly flammable <sup>(1)</sup>                                |    |
| A substance which is a liquid having a flash point ≥21 C and ≤55 C, except a liquid which when tested at 55 C in the manner described in Schedule 2 to the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972 does not support combustion.                                                                                                                                                                                                                                                                               | Flammable <sup>(1)</sup>                                       | No symbol required                                                                    |
| A substance which if it is inhaled or ingested or it penetrates the skin, may involve extremely serious acute or chronic health risks and even death.                                                                                                                                                                                                                                                                                                                                                                                         | Very toxic <sup>(2)</sup>                                      |  |
| A substance which if it is inhaled or ingested or it penetrates the skin, may involve serious acute or chronic health risks and even death.                                                                                                                                                                                                                                                                                                                                                                                                   | Toxic <sup>(2)</sup>                                           |  |
| A substance which if it is inhaled or ingested or it penetrates the skin, may involve limited health risks.                                                                                                                                                                                                                                                                                                                                                                                                                                   | Harmful <sup>(2)</sup>                                         |  |
| A substance which may on contact with living tissues destroy them.                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Corrosive                                                      |  |
| A non-corrosive substance which, through immediate, prolonged or repeated contact with the skin or mucous membrane, can cause inflammation.                                                                                                                                                                                                                                                                                                                                                                                                   | Irritant                                                       |  |

<sup>(1)</sup> Preparations packed in aerosol dispensers shall be classified as flammable in accordance with Part III of this schedule.

<sup>(2)</sup> Substances shall be classified as very toxic, toxic or harmful in accordance with the additional criteria set out in Part II of this schedule.

**Table 14.6 Classification of and hazard warning signs for substances dangerous for conveyance (Schedule 2 Part I)**

| <i>Characteristic properties of the substance</i>                                                                                                                                                                                                                                                                                                                                                                        | <i>Classification</i>               | <i>Hazard warning sign</i>                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|---------------------------------------------------------------------------------------|
| <p>A substance which</p> <p>(a) has a critical temperature <math>&lt;50^{\circ}\text{C}</math> or which at <math>50^{\circ}\text{C}</math> has a vapour pressure of more than 3 bar absolute and</p> <p>(b) is conveyed by road at a pressure of more than 500 millibars above atmospheric pressure or in liquefied form other than a toxic gas or a flammable gas.</p>                                                  | Non-flammable compressed gas        |    |
| <p>A substance which has a critical temperature <math>&lt;50^{\circ}\text{C}</math> or which at <math>50^{\circ}\text{C}</math> has a vapour pressure of more than 3 bar absolute and which is toxic.</p>                                                                                                                                                                                                                | Toxic gas                           |    |
| <p>A substance which has a critical temperature <math>&lt;50^{\circ}\text{C}</math> or which at <math>50^{\circ}\text{C}</math> has a vapour pressure of more than 3 bar absolute and is flammable.</p>                                                                                                                                                                                                                  | Flammable gas <sup>(1)</sup>        |    |
| <p>A liquid with a flash point <math>\leq 55^{\circ}\text{C}</math> except a liquid which</p> <p>(a) has a flash point <math>\geq 21^{\circ}\text{C}</math> and <math>\leq 55^{\circ}\text{C}</math> and</p> <p>(b) when tested at <math>55^{\circ}\text{C}</math> in the manner described in Schedule 2 to the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972 does not support combustion.</p> | Flammable liquid <sup>(1,2)</sup>   |   |
| <p>A solid which is readily combustible under conditions encountered in conveyance by road or which may cause or contribute to fire through friction.</p>                                                                                                                                                                                                                                                                | Flammable solid                     |  |
| <p>A substance which is liable to spontaneous heating under conditions encountered in conveyance by road or to heating in contact with air being then liable to catch fire.</p>                                                                                                                                                                                                                                          | Spontaneously combustible substance |  |

Table 14.6 Cont'd

| <i>Characteristic properties of the substance</i>                                                                                                                                                              | <i>Classification</i>                                     | <i>Hazard warning sign</i>                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|---------------------------------------------------------------------------------------|
| A substance which in contact with water is liable to become spontaneously combustible or to give off a flammable gas.                                                                                          | Substance which in contact with water emits flammable gas |    |
| A substance other than an organic peroxide which, although not itself necessarily combustible, may by yielding oxygen or by a similar process cause or contribute to the combustion of other material.         | Oxidizing substance                                       |    |
| A substance which is<br>(a) an organic peroxide and<br>(b) an unstable substance which may undergo exothermic self-accelerating decomposition.                                                                 | Organic peroxide                                          |    |
| A substance known to be so toxic to man as to afford a hazard to health during conveyance or which, in the absence of adequate data on human toxicity, is presumed to be toxic to man.                         | Toxic substance                                           |   |
| A substance known to be toxic to man or, in the absence of adequate data on human toxicity, is presumed to be toxic to man but which is unlikely to afford a serious acute hazard to health during conveyance. | Harmful substance                                         |  |
| A substance which by chemical action will<br>(a) cause severe damage when in contact with living tissue;<br>(b) materially damage other freight or equipment if leakage occurs.                                | Corrosive substance                                       |  |

Table 14.6 Cont'd

| <i>Characteristic properties of the substance</i>                                                                                                                                                                                                         | <i>Classification</i>     | <i>Hazard warning sign</i>                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-------------------------------------------------------------------------------------|
| A substance which is listed in Part 1A of the approved list and which may create a risk to the health or safety of persons in the conditions encountered in conveyance by road, whether or not it has any of the characteristic properties set out above. | Other dangerous substance |  |
| Packages containing two or more dangerous substances which have different characteristic properties.                                                                                                                                                      | Mixed hazards             |  |

<sup>(1)</sup> An aerosol which is flammable in accordance with paragraph 2 or Part III of Schedule 1 shall have the classification of a flammable gas. Other aerosols need not be classified as flammable gas or flammable liquid.

<sup>(2)</sup> Viscous preparations which comply with the conditions in Part III of this schedule shall not be required to be classified as flammable.

Table 14.7 Criteria for the toxicity classification of substances

| <i>Category<sup>(1)</sup></i> | <i>LD<sub>50</sub> absorbed orally in rat (mg/kg)</i> | <i>LD<sub>50</sub> absorbed percutaneously in rat or rabbit (mg/kg)</i> | <i>LC<sub>50</sub> absorbed by inhalation in rat (mg/l, 4 hr)</i> |
|-------------------------------|-------------------------------------------------------|-------------------------------------------------------------------------|-------------------------------------------------------------------|
| Very toxic                    | ≤25                                                   | ≤50                                                                     | ≤0.5                                                              |
| Toxic                         | >25 to 200                                            | >50 to 400                                                              | >0.5 to 2                                                         |
| Harmful                       | >200 to 2000                                          | >400 to 2000                                                            | >2 to 20                                                          |

<sup>(1)</sup> 'Very toxic', 'toxic' or 'harmful', applied to a dangerous substance not classified in accordance with Schedules 3, 4 and 5, means that the substance has a toxicity falling within the range tabulated for that category.

**Note**

If a substance produces other effects that make it inadvisable to use the LD<sub>50</sub> or LC<sub>50</sub> value as the principal basis of classification, the substance should be classified according to the magnitude of these effects.

Table 14.8 Hazard classification of explosives (UK)\*

| <i>Division</i>                                                                                                                              | <i>Division No.</i> |
|----------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| Substances and articles that have a mass explosion hazard                                                                                    | 1.1                 |
| Substances and articles that have a projection hazard but not a mass explosion hazard                                                        | 1.2                 |
| Substances and articles that have a fire hazard and either a minor blast hazard or a minor projection hazard but not a mass explosion hazard | 1.3                 |
| Substances and articles that present no significant hazard                                                                                   | 1.4                 |
| Very insensitive substances that have a mass explosion hazard                                                                                | 1.5                 |
| Extremely insensitive articles which do not have a mass explosion hazard                                                                     | 1.6                 |

\*See also UN recommendations on transportation of dangerous goods and the IARTA Regulations (page 460).

**Table 14.9 Compatibility groups for explosives (UK)**

| <i>Compatibility group</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <i>Designating letter</i> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| Primary explosive substance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | A                         |
| Article containing a primary explosive substance and not containing two or more independent safety features                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | B                         |
| Propellant explosive substance or other deflagrating explosive substance or article containing such explosive substance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | C                         |
| Secondary detonating explosive substance or black powder or article containing a secondary detonating explosive substance, in each case without means of initiation and without a propelling charge, or article containing a primary explosive substance and containing two or more independent safety features                                                                                                                                                                                                                                                                                                                                               | D                         |
| Article containing a secondary detonating explosive substance, without means of initiation and with a propelling charge (other than a charge containing a flammable or hypergolic liquid)                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | E                         |
| Article containing a secondary detonating explosive substance, with means of initiation and either with a propelling charge (other than a charge containing a flammable or hypergolic liquid) or without a propelling charge                                                                                                                                                                                                                                                                                                                                                                                                                                  | F                         |
| A substance that is an explosive substance because it is designed to produce an effect by heat, light, sound, gas or smoke or a combination of these as a result of non-detonative self-sustaining exothermic chemical reactions or an article containing such a substance which is explosive because it is capable by chemical reaction in itself of producing gas at such a temperature and pressure and at such a speed as could cause damage to surroundings and an illuminating, incendiary, lachrymatory or smoke-producing substance (other than a water-activated article or one containing white phosphorus, phosphide or a flammable liquid or gel) | G                         |
| Article containing both an explosive substance and white phosphorus                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | H                         |
| Article containing both an explosive substance and a flammable liquid or gel                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | J                         |
| Article containing both an explosive substance and a toxic chemical agent                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | K                         |
| Explosive substance or explosive article presenting a special risk needing isolation of each type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | L                         |
| Substance or article so packed or designed that any hazardous effect arising from accidental functioning is confined within the package unless the package has been degraded by fire, in which case all blast or projection effects are limited to the extent that they do not significantly hinder or prohibit fire-fighting or other emergency response efforts in the immediate vicinity of the package                                                                                                                                                                                                                                                    | S                         |

Plant protection products.

Cosmetics.

Foodstuffs including additives and flavourings.

Animal feeding stuffs.

Radioactive substances.

Waste substances.

Substances in transit under customs supervision.

Substances classed as 'no longer polymers'. These are listed polymers which were considered to be polymers under the NONS 82 definition but not by the NONS 93 version. Unlisted substances *may* also be exempt if they could have been considered under NONS 82, or are not a polymer under NONS 93, or were placed on the market between 1 January 1971 and 1 November 1993.

**Table 14.10 Minimum information for a Material Safety Data Sheet***Identification*

Identification of product by trade name. Supplier's name and address plus a telephone number (for emergencies).

*Chemical composition*

Chemical composition; details of ingredients, formulae and proportions, including measures to be taken for over-exposure to eyes/skin or by inhalation/ingestion/absorption. Information for medical treatment.

*Disposal – normal and emergency spills*

General precautions, disposal methods and statutory controls.

Clean-up, neutralization, disposal methods for spills.

*Fire and explosion hazards and precautions*

Flammable limits, flash point, auto-ignition temperature etc.

Reactivity, stability.

Fire-fighting procedures.

*Health hazards*

Acute (short-term) effects and chronic (long-term) effects.

Special hazards.

First detectable signs of over-exposure by all means of entry.

*Environmental hazards**Test data**Exposure limits*

Threshold Limit Values or Occupational Exposure Limits (preferably with reference to their interpretation, i.e. not as 'safe' levels).

For mixtures – reference to prediction, or substance used for basis.

*Legal requirements*

Any legislation applicable to safe handling, storage and use.

*Control measures*

Containment, ventilation, means of limiting exposure generally.

*Personal protection*

Identify requirements and circumstances for use.

Emergency requirements.

*Storage and handling*

Conditions of storage, segregation, materials of construction.

Types of container and handling precautions.

Where relevant, procedures for disposal of containers, e.g. aerosol dispensers, drums when 'empty'.

*References*

References consulted and further sources of information.

**Table 14.11 Headings for information supplied on a Safety Data Sheet**

Identification of the substance/preparation and company

Composition/information on ingredients

Hazards identification

First-aid measures

Fire-fighting measures

Accidental release measures

Handling and storage

Exposure controls/personal protection

Physical and chemical properties

Stability and reactivity

Toxicological information

Ecological information

Disposal consideration

Transport information

Regulatory information

Other information



Substances intended solely for scientific research and development in quantities less than 100 kg per year.

Substances placed on the market for process-orientated research and development with a limited number of customers registered with the notifier.

The aim of the notification systems is to identify possible risks posed to people and the environment from placing new substances on the market. A notification comprises:

- data on the chemical identity of the substance;
- an estimate of the quantity of the substance to be placed on the EC market;
- details of the functions and uses of the substance;

**Table 14.12 Notification bands\***

| <i>Type of notification</i>  | <i>Information requirements</i>                                                                                                                                                                                                                                         | <i>Quantity placed on the market</i> |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| Deemed to have been notified | – 0 kg                                                                                                                                                                                                                                                                  |                                      |
| REDUCED                      | Acute toxicity<br>Indications for use<br>Chemical identity                                                                                                                                                                                                              | 10 kg                                |
| REDUCED                      | Additional acute toxicity<br>Acute daphnia toxicity<br>Biodegradability<br>Physico-chemical properties                                                                                                                                                                  | 100 kg/annum or 500 kg cumulative    |
| BASE SET                     | Mutagenicity<br>Toxicity to reproduction<br>Toxicity to algae<br>Acute daphnia and fish toxicity<br>Abiotic and readily biotic degradability<br>Additional physico-chemical properties                                                                                  | 1 t/annum or 5 t cumulative          |
| ‘Lower’ LEVEL 1              | Possibly some of the information from ‘Upper’ LEVEL 1                                                                                                                                                                                                                   | 10 t/annum or 50 t cumulative        |
| ‘Upper’ LEVEL 1              | Chronic toxicity<br>Toxicity in soil and plants<br>Additional mutagenicity<br>Long-term toxicity<br>Bioaccumulation<br>Inherent biodegradability<br>Additional abiotic degradability                                                                                    | 100 t/annum or 500 t cumulative      |
| LEVEL 2                      | Carcinogenicity<br>Additional chronic toxicity<br>Additional environmentally dangerous properties<br>Toxicity to birds<br>Long-term toxicity in water and soil<br>Degradability simulation tests<br>Additional abiotic degradability<br>Mobility in water, soil and air | 1000 t/annum or 5000 t cumulative    |

\*A complete list of the information required for each type of notification is given in Schedules 2 and 3 of the Regulations.

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physico-chemical, toxicological and ecotoxicological properties of the substance;  
recommended precautions, disposal and emergency procedures;  
proposals for classification and labelling.

The notification dossier may also contain a risk assessment prepared by the notifier. The precise contents of a notification will depend on, e.g., the quantity of the substance to be placed on the market and, to an extent, on the properties and uses of the substance. The thresholds for notification and a summary of the information requirements are given in Table 14.12.

All testing to support notification must be performed by methods specified in Annex V to Directive 79/831/EEC and in accordance with the principles of good laboratory practice (GLP). GLP is concerned with the organizational processes and conditions under which laboratory studies are planned, performed, monitored, recorded and reported.

Laboratories wishing to claim GLP compliance are normally registered with Competent Authorities who issue statements of compliance following successful periodic inspections of the premises to monitor compliance with the relevant legislation. In the UK compliance with the Good Laboratory Practice Regulations 1999 is audited by the Medicines Control Agency.

# Transport of chemicals

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Transportation of a chemical between the supplier and/or agent and the user may introduce special risks in addition to those which can arise from the inherent chemical and physical properties. Comprehensive labelling and identification procedures, and information supply, covered in Chapter 14, aim to avoid any confusion over the nature of the chemical and recommended handling, storage and emergency procedures. However, different parties have to oversee, and take responsibility for, the chemical at different stages during its movement between sites, e.g. loading/storage, transport by various methods, storage in transit, unloading. Moreover, third parties can be prone to injury, and property or the environment can be subjected to damage, if loss of containment occurs. Security is a concern throughout.

The transportation of chemicals is therefore highly regulated. In addition to general transport legislation numerous statutory provisions govern the carriage of hazardous substances by air, road, rail and sea. These tend to address the need for:

- documentation;
- suitability of container, examination, testing and certification of tanks;
- classification, packaging and labelling of dangerous goods;
- carriage information;
- duties of consignors, operators, drivers, etc.;
- adequate information and warning labels to be displayed on containers, tanks, and wagons;
- training of crews/drivers and others engaged in the transport process;
- loading and unloading;
- security and other safety measures including emergency arrangements;
- special requirements.

Some categories of hazardous materials are covered by specific regulations as exemplified in the UK by the Carriage of Explosives by Road Regulations 1996; the Radioactive Material (Road Transport) (Great Britain) Regulations 1996; and the Packaging, Labelling and Carriage of Radioactive Material by Rail Regulations 1996. It is the duty of all those engaged in the transportation of hazardous chemicals to identify the relevant legislation and to comply with all appropriate detailed requirements. In addition to local legislation and guidance, the transportation of chemicals by air, rail, road and sea is the subject of international conventions, e.g. the Intergovernmental Marine Consultative Organization Dangerous Goods Code, European Agreement concerning the International Carriage of Dangerous Goods by Road, The International Regulations concerning the Carriage of Dangerous Goods by Rail, and the International Air Transport Association Restricted Articles Regulations. Table 15.12 lists dangerous goods forbidden for transport by air.

This chapter provides an insight into general principles associated with the transportation of hazardous substances; reference is made to selected regulations for illustrative purposes.

Irrespective of the mode of carriage, the safe transport of chemicals is the responsibility of:

the producer;  
any hauliers involved; and  
the recipient, e.g. during unloading.

Effective communication between them is a vital consideration.

## Road transport

### *Dangerous substances*

Typical division of responsibilities in a road transport operation are shown in Figure 15.1. Producers transporting their own products need to establish a system to ensure that all necessary information and instructions are provided for safe handling under all foreseeable conditions. This will require:

The enforcement of codes of practice, working procedures and general instructions incorporating all possible safety factors.

Specific training and instruction of transport staff on actions to be taken in emergencies, e.g. fire, spillage on land, spillage entering drains.

The institution, or development in consultation with the customer, of a safe unloading procedure (e.g. as exemplified in Table 15.18 for non-pressurized hazardous liquids).

These need to comply with all statutory legislation relevant to the specific chemical (e.g. if dangerous substances are carried into a UK port the operator must, under the Dangerous Substances in Harbour Areas Regulations 1987, give prior notice to the Harbour Master and in some cases the berth operator). The vehicles must be of the correct design and construction for the load carried and be maintained in sound condition. Various regulations, codes of practice and guidelines cover the labelling of containers and vehicles to identify the substances and their hazards in an emergency.

In the UK, the conveyance by road of dangerous chemicals in road tankers of any capacity and in tanks exceeding 3 m<sup>3</sup> is controlled by the Carriage of Dangerous Goods by Road Regulations 1996 as amended. Dangerous substances are defined as those named in an approved list or falling into the classifications in a schedule. Except for a slightly different definition for 'other dangerous substances' and 'multi-load', the latter classification is similar to that in Table 14.1.

Conveyance includes loading, transportation, unloading, cleaning and purging. A check-list of selected operator duties (excluding duties in relation to the unloading of petroleum spirit, covered by Schedule 4) arising where appropriate under these regulations is given in Table 15.1. The regulations also provide instruction on the form of hazard warning labels (Figure 15.2). In the event of an emergency, drivers should normally carry out the actions listed in Table 15.2.

The provision of written instructions in the form of a TREMCARD developed by CEFIC is exemplified by Figure 15.3.

### *Explosives*

For the carriage of explosives by road the nature of the substance, the suitability of both the container and vehicle, and the quantity of explosive carried are paramount considerations. Private

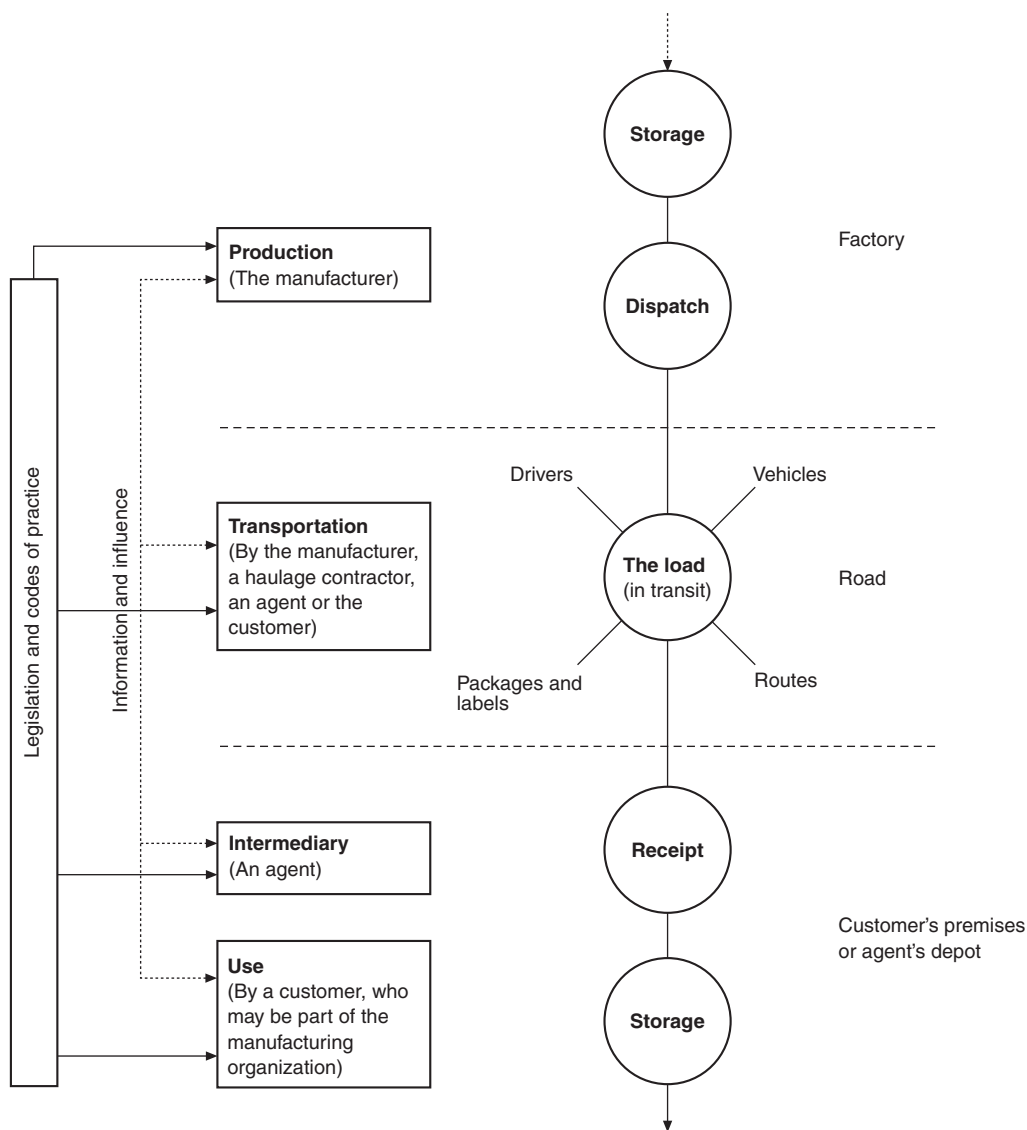


**Figure 15.1** Responsibilities for safe transport of chemicals by road

light goods vehicles may be suitable only for small quantities of explosives (other than those in Compatibility Group S) and an ordinary goods vehicle is suitable for an intermediate quantity of most types of explosives. However, specially constructed vehicles are essential for more dangerous types of explosives or for the largest loads permitted under regulations. Cognizance must be taken of whether the vehicle is fuelled by diesel oil, petrol or LPG and whether or not it is an articulated vehicle. For the purposes of the UK Carriage of Explosives by Road Regulations 1996, road vehicles are classified as I, II or III (Table 15.3 – with type I defined as a vehicle other than type II or III). The characteristics of type II and III vehicles are also summarized in Table 15.3. (Whilst specialized, this illustrates the range of design features available for vehicles carrying thermally-unstable chemicals generally.) The selection of vehicle for a particular task will be influenced by

**Table 15.1 Selected Operator duties under the Carriage of Dangerous Goods by Road Regulations 1996\***

|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Operator of tanker or tank container | <p>Ensure compliance with requirements specified in relevant approved documents and schedules to the regulations.</p> <p>Dangerous goods only transported if the letter Y appears in appropriate columns of Approved Carriage list and Schedules 5 and 6 are complied with, and tank pressures do not exceed the maximum working pressure as per certifications.</p> <p>Ensure specialist advice is always available on hazardous contents.</p> <p>Ensure the tank, container or vehicle is suitable for journey taking cognizance of the properties and volume of load.</p> <p>Ensure the vehicle has no more than one trailer or semi-trailer.</p> <p>Ensure packages of sensitive materials are suitably protected.</p> <p>Ensure tanks are certified by competent authority/approved person.</p> <p>Pass tank certificates to new owner when ownership changes.</p> <p>Obtain consignor's declaration where relevant.</p> <p>Obtain from consignor information listed in Section 13.</p> <p>Take reasonable steps to ensure goods are fit for carriage.</p> <p>Not permit driver to;</p> <ul style="list-style-type: none"> <li>carry anyone other than crew member;</li> <li>open package unless authorized;</li> <li>bring sources of ignition into vehicle;</li> <li>carry food unless adequately protected.</li> </ul> <p>Provide sub-contract operators and drivers relevant information from Section 14.</p> <p>Display information as per Schedule 10.</p> <p>Keep transport documentation relating to each journey for 3 months after completion of journey.</p> <p>Prevent carriage of materials which are liable to explosion.</p> <p>Ensure loading, stowage, unloading and cleaning of containers, tanks and containers creates no additional risk.</p> <p>Clean contaminated vehicles before re-loading.</p> <p>Establish emergency and parking arrangements as set out in Part VI.</p> |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

\*The full SI 1996 No. 2095 should be consulted for complete details.

the explosive Division Group (see Table 14.8), the Compatibility Group (see Table 14.9) and the quantity to be transported, as summarized by Table 15.4.

### ***Radioactive substances***

The transportation of radioactive material by road in the UK is prohibited:

|             |   |             |
|-------------|---|-------------|
| 1<br>Orange | 3 |             |
| 2<br>Orange |   |             |
| 4<br>Orange |   | 5<br>Orange |

**Figure 15.2** Hazard warning panels and labels

- Space 1 **Emergency action codes** specified for that substance in Column 3 of Part 1 of the approved list
- Space 2 **Substance identification number and name** as specified for that substance in Part 1 of the approved list
- Space 3 **Hazard warning sign for the classification** of the substance as specified in Part 1 of the approved list
- Space 4 **Telephone number** where expert advice can be obtained at all times when the substance is being conveyed by road
- Space 5 **Name of the manufacturer or owner** of the substance

**Table 15.2** Emergency procedures for drivers

Arrange for the police and emergency services to be alerted

Arrange for assistance to be given to any person injured or in immediate danger

If considered safe to do so – having regard to the nature of the emergency, the substance and the emergency equipment available – follow a selection of the following procedures in an appropriate order:

Stop the engine

Turn off any battery isolating switch

If there is no danger of ignition, operate the emergency flashing device

Move the vehicle to a location where any leakage would cause less harm

Wear appropriate protective clothing

Keep onlookers away

Place a red triangle warning device at the rear of the vehicle and near any spillage

Prevent smoking and direct other vehicles away from any fire risk area

Upon the police/fire brigade taking charge:

Show the written information, e.g. Tremcard, to them

Tell them of action taken and anything helpful about the load, etc.

At the end of the emergency, inform the operator.

The written information given to the driver should include:

The name of the substance

Its inherent dangers and appropriate safety measures

Action and treatment following contact/exposure

Action in the event of fire and fire-fighting equipment to be used

Action following spillage on the road

How and when to use any special safety equipment

in a public service vehicle;

in a vehicle carrying explosives;

generally in damaged packages;

if inadequately labelled.

Radiation limits for individual packages for shipment by road are dictated by the type of package and the activity of the radionuclide. The Radioactive Material (Road Transport) (Great Britain) Regulations provide rules for calculating package limits. Radiation limits for road consignments in the UK under 'exclusive use' are given in Table 15.5. Instructions are provided on restrictions;

|                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                            |                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| UN No. 1088                                                                                                                                                                                                                                                                                                                                                                             | <b>TRANSPORT EMERGENCY CARD</b><br>(Road)                                                                                                                                                                                                                                                                                                                                                  | CEPIC TEC (R)-687<br>April 1974<br>Class IIIa ADR |
| Cargo                                                                                                                                                                                                                                                                                                                                                                                   | ACETAL<br>(Acetaldehyde Diethyl Acetal)<br>Colourless liquid with perceptible odour.<br>Immiscible with water, lighter than water.                                                                                                                                                                                                                                                         |                                                   |
| Nature of hazard                                                                                                                                                                                                                                                                                                                                                                        | Highly inflammable (flashpoint below 21 °C).<br>Volatile.<br>The vapour is invisible, heavier than air and spreads along ground.<br>Can form explosive mixture with air particularly in empty uncleaned receptacles.<br>Heating will cause pressure rise, with risk of bursting and subsequent explosion.<br>The vapour has narcotic effect.<br>The substance has irritant effect on eyes. |                                                   |
| Protective devices                                                                                                                                                                                                                                                                                                                                                                      | Goggles giving complete protection to eyes.<br>Plastic or rubber gloves.<br>Eyewash bottle with clean water.                                                                                                                                                                                                                                                                               |                                                   |
| EMERGENCY ACTION – Notify police and fire brigade immediately                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                            |                                                   |
|                                                                                                                                                                                                                                                                                                                                                                                         | Stop the engine<br>No naked lights. No smoking<br>Mark roads and warn other road users<br>Keep public away from danger area<br>Use explosion-proof electrical equipment<br>Keep upwind                                                                                                                                                                                                     |                                                   |
| Spillage                                                                                                                                                                                                                                                                                                                                                                                | Shut off leaks if without risk<br>Absorb in earth or sand and remove to safe place<br>Subsequently flush road with water<br>Prevent liquid entering sewers, basements and workpits, vapour may create explosive atmosphere<br>Warn inhabitants – explosion hazard<br>If substance has entered a water course or sewer or contaminated soil or vegetation, advise police                    |                                                   |
| Fire                                                                                                                                                                                                                                                                                                                                                                                    | Keep containers cool by spraying with water if exposed to fire<br>Extinguish with water spray, dry chemical, alcohol foam or halons<br>Do not use water jet                                                                                                                                                                                                                                |                                                   |
| First aid                                                                                                                                                                                                                                                                                                                                                                               | Remove soaked clothing immediately and wash affected skin with plenty of water<br>If substance has got into the eyes, immediately wash out with plenty of water for several minutes<br>Seek medical treatment when anyone has symptoms apparently due to inhalation or contact with eyes                                                                                                   |                                                   |
| Additional information provided by manufacturer or sender                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                            |                                                   |
| TELEPHONE<br>Prepared by CEPIC (CONSEIL EUROPEAN DES FEDERATIONS DE L'INDUSTRIE CHIMIQUE, EUROPEAN COUNCIL OF CHEMICAL MANUFACTURER'S FEDERATIONS)<br>Zurich, from the best knowledge available: no responsibility is accepted that the information is sufficient or correct in all cases. Obtainable from NORPRINT LIMITED, BOSTON, LINCOLNSHIRE<br>Applied only during road transport |                                                                                                                                                                                                                                                                                                                                                                                            |                                                   |

English

English

Figure 15.3 CEPIC TREMCARD



**Table 15.3 Characteristics of type II and type III vehicles for carriage of explosives**

| <i>Feature</i>                    | <i>Type II</i>                                                                                                                                                                                                                                                  | <i>Type III</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General construction requirements | <p>Compression ignition engine</p> <p>Designed, constructed and equipped to protect explosive from external hazards and weather</p> <p>Closed or securely sheeted</p> <p>Trailers to be adequately braked or restrained upon detachment from towing vehicle</p> | <p>Compression ignition engine</p> <p>Vehicle design to be closed with loading surface continuous.</p> <p>Special attention to heat-resistant and fire-proofing properties of the body. Doors all lockable and placed and constructed as to overlap joints</p> <p>Any trailers to be fitted with effective braking system acting on all wheels, actuated by the towing vehicle and automatically upon breakage of the coupling. Trailers equipped with only inertia braking devices limited to a maximum load of 50 kg net explosive mass</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Electrical requirements           | <p>Max. rated voltage of 24 V</p> <p>Electrical installation of load-carrying compartment to be dust-protected (at least IP54 or equivalent) or in case of Compatibility Group J (see Table 14.9) flame-proof Ex d (at least IP65 or equivalent)</p>            | <p>Max. rated voltage of 24 V</p> <p>Electrical installation of load-carrying compartment to be dust-protected (at least IP54 or equivalent) or in case of Compatibility Group J (see Table 14.9) flame-proof Ex d (at least IP65 or equivalent)</p> <p><i>Wiring</i></p> <p>Conductors of sufficient size so as to prevent overheating, and adequately insulated. All circuits to be protected by fuses or automatic circuit breakers, except for specified battery connections</p> <p>Cables securely fastened and positioned so that conductors are adequately protected against mechanical and thermal stresses</p> <p><i>Battery master switch</i></p> <p>A switch to break electrical circuits placed as close as possible to the battery</p> <p>Readily accessible, distinctively marked</p> <p>direct or indirect control devices installed, one in driver's cab and one on outside of vehicle. The cab version shall be within immediate reach, but protected against inadvertent operation</p> <p>Switch should not constitute a fire risk in an explosive atmosphere and be capable of opening whilst engine is running, without causing any dangerous excess voltage</p> <p>IP54 protection for cable connections on battery master switch</p> <p>Battery terminals should be electrically insulated or covered by insulated battery box cover.</p> <p>Batteries not located under bonnet to be fitted in vented box</p> |

Table 15.3 Cont'd

| <i>Feature</i>  | <i>Type II</i>                                                                                                                                         | <i>Type III</i>                                                                                                                                                                                                                                                            |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fire prevention | <i>Vehicle cab</i><br>Driver's cab constructed of material not readily flammable                                                                       | <i>Tachograph</i><br>Electrical supply provided via safety barrier connected directly to battery and all the equipment certified to EN 50 020                                                                                                                              |
|                 | <i>Fuel tank</i><br>Tanks supplying the engine to be constructed so that fuel leakages drain to ground without contact of hot parts of vehicle or load | <i>Electrical installations at rear of driver's cab</i><br>Designed, constructed, installed and protected so as to prevent ignition or short-circuit under normal conditions of use, and risks minimized upon impact or deformation                                        |
|                 | <i>Engine</i><br>Engine to be located forward of the load compartment (or under the load such that excess heat poses no hazard to the load)            | <i>Vehicle cab</i><br>Driver's cab constructed of material not readily flammable                                                                                                                                                                                           |
|                 | <i>Exhaust system</i><br>Constructed and located such that excess heat poses no hazard to load                                                         | <i>Fuel tank</i><br>Tanks supplying the engine to be constructed so that fuel leakages drain to ground without contact of hot parts of vehicle or load                                                                                                                     |
|                 |                                                                                                                                                        | <i>Engine</i><br>Engine to be located forward of the load compartment (or under the load such that excess heat poses no hazard to the load)                                                                                                                                |
|                 |                                                                                                                                                        | <i>Exhaust system</i><br>Constructed and located such that excess heat poses no hazard to load                                                                                                                                                                             |
|                 |                                                                                                                                                        | <i>Vehicle endurance brake</i><br>Systems emitting high temperatures placed behind the rear wall of the cab to be equipped with thermal shield appropriately fixed and located<br>The thermal shield should protect the braking system from outflow or leakage of the load |
|                 | <i>Combustion heaters</i><br>Prohibited with certain specified exceptions for cabs                                                                     | <i>Combustion heaters</i><br>Prohibited with certain specified exceptions for cabs                                                                                                                                                                                         |

marking, labelling and placarding; contamination levels; prior approval; quality assurance programmes; test procedures; documentation; stowing and responsibilities. For example, during the transport of radioactive material the driver should:

- ensure none of the material is lost, escapes, or is unlawfully removed;
- not leave the vehicle unattended in a place to which the public has access;
- generally not park the vehicle for a continuous period of longer than one hour unless when parked there is clear space of at least 2 metres on both sides and at both ends of the vehicle;
- keep on the vehicle transport documentation until the package has been delivered.

The driver must notify the police and consignor in the event of an emergency such as material loss, escape or unlawful removal; if package has been opened or damaged, or if the vehicle has overturned, suffered serious damage, or is involved in a fire.

**Table 15.4 Choice of vehicle to match the proposed load of explosive**

| <i>Division<br/>(see Table 14.8)</i> | <i>Compatibility group<br/>and form (see Table 14.9)</i> | <i>Special goods<br/>vehicle</i> | <i>Ordinary goods<br/>vehicle</i> | <i>Private light<br/>goods vehicle</i> |
|--------------------------------------|----------------------------------------------------------|----------------------------------|-----------------------------------|----------------------------------------|
| 1.1                                  | A                                                        | 50 kg                            | Nil                               | Nil                                    |
|                                      | Substances of G                                          | 5 tonnes                         | 50 kg                             | 1 kg                                   |
|                                      | B                                                        | 5 tonnes                         | 500 kg                            | 10 kg                                  |
|                                      | Substances of C or D                                     | 16 tonnes                        | 500 kg                            | 50 kg                                  |
|                                      | F                                                        | 5 tonnes                         | 50 kg                             | 50 kg                                  |
|                                      | Articles of G                                            | 5 tonnes                         | 5 tonnes                          | 50 kg                                  |
|                                      | Articles of C, D, E or J                                 | 16 tonnes                        | 5 tonnes                          | 50 kg                                  |
|                                      | Articles of L                                            | 5 tonnes                         | 5 tonnes                          | 50 kg                                  |
| 1.2                                  | Any                                                      | 16 tonnes                        | 5 tonnes                          | 50 kg                                  |
| 1.3                                  | Any                                                      | 16 tonnes                        | 5 tonnes                          | 50 kg                                  |
| 1.4                                  | B, C, D, E, F or G                                       | 16 tonnes                        | 16 tonnes                         | 50 kg                                  |
|                                      | S                                                        | Unlimited                        | Unlimited                         | Unlimited                              |
| 1.5                                  | D                                                        | 16 tonnes                        | 5 tonnes                          | 50 kg                                  |
| 1.6                                  | N                                                        | 16 tonnes                        | 5 tonnes                          | 50 kg                                  |
| *                                    | *                                                        | 500 kg                           | 50 kg                             | 10 kg                                  |

\* Unclassified explosives carried solely in connection with an application for their classification.

**Table 15.5 Radiation levels for a road consignment of radioactive material under 'exclusive use'**

The radiation level for a consignment transported under exclusive use by a vehicle shall not exceed:

- (a) 10 mSv/h at any point on the external surface of any package or overpack, and may only exceed 2 mSv/h provided that:
  - (i) the vehicle by which the consignment is transported is equipped with an enclosure which, during routine transport, prevents the access of unauthorized persons to the interior of the enclosure;
  - (ii) provisions are made to secure the package or overpackage so that its position within the vehicle remains fixed during routine transport; and
  - (iii) there are no loading or unloading operations between the beginning and the end of the shipment;
- (b) 2 mSv/h at any point on the outer surfaces of the vehicle, including the upper and lower surfaces, or in the case of an open vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load, and on the lower external surface of the vehicle; and
- (c) 0.1 mSv/h at any point 2 m from the vertical planes represented by the outer lateral surfaces of the vehicle, or, if the load is transported in an open vehicle, at any point 2 m from the vertical planes projected from the outer edges of the vehicle.

## Rail transport

### *Dangerous substances and explosives*

The carriage of hazardous chemicals by rail in the UK is governed by, e.g., the Carriage of Dangerous Goods by Rail Regulations 1996. These regulations cover the transport in bulk in wagons and large containers, small containers and carriage in tanks. Mixed loading of certain goods is prohibited. Packages bearing a danger sign with a classification code specified in column 1 of Table 15.6 shall not be loaded in the same container or wagon with any package or small container bearing a danger sign with any classification codes specified in column 2. Small containers bearing danger signs and classifications in column 1 must not be loaded in the same container or wagon with packages or small containers bearing danger signs and classification codes in column

**Table 15.6 Prohibition on mixed loads of dangerous goods (see Footnote and Table 14.8)**

| <i>Column 1</i><br><i>Classification code</i> | <i>Column 2</i><br><i>Classification code</i>      |
|-----------------------------------------------|----------------------------------------------------|
| 1, 1.4, 1.5, 1.6 or 01                        | 2, 3, 4.1, 4.2, 4.3, 5.1, 5.2, 6.1, 6.2, 7, 8 or 9 |
| 2                                             | 1, 1.4, 1.5, 1.6 or 01                             |
| 3                                             | 1, 1.4, 1.5, 1.6 or 01                             |
| 4.1                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 4.2                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 4.3                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 5.1                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 5.2                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 6.1                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 6.2                                           | 1, 1.4, 1.5, 1.6 or 01                             |
| 8                                             | 1, 1.4, 1.5, 1.6 or 01                             |
| 9                                             | 1, 1.4, 1.5, 1.6 or 01                             |

\*Consult the original regulations, regulations concerning the International Carriage of Dangerous Goods by Rail 1997, UN recommendations on transportation of dangerous goods, and IARTA Regulations (page 460).

| <i>Classification code</i> | <i>Type</i>                                                |
|----------------------------|------------------------------------------------------------|
| 1                          | Explosive substances and articles                          |
| 2                          | Gases: compressed liquefied or dissolved under pressure    |
| 3                          | Flammable liquids                                          |
| 4.1                        | Flammable solids                                           |
| 4.2                        | Substances liable to spontaneous combustion                |
| 4.3                        | Substances when in contact with water emit flammable gases |
| 5.1                        | Oxidizing substances                                       |
| 5.2                        | Organic peroxides                                          |
| 6.1                        | Toxic substances                                           |
| 6.2                        | Infectious substances                                      |
| 7                          | Radioactive materials                                      |
| 8                          | Corrosive substances                                       |
| 9                          | Miscellaneous dangerous substances                         |

2. The carriage of temperature-controlled substances by rail is prohibited and special requirements are included for the carriage of explosives including:

Prohibition of carriage in open containers.

Restriction on the classification of explosive that can be transported and how, including the need for sheet steel spark-guards for carriage of certain explosives.

Limitation on the quantity of material transported. Thus, Compatibility Group A materials are not permitted. Other than explosives in Division 1.4, the maximum quantity of explosive permitted in any container or wagon is 20 tonnes net explosive content. Materials in column 1 of Table 15.7 must not be transported in adjacent containers of wagons with materials in column 2 in amounts exceeding those quoted. (Where a train comprises more than one such group of adjacent containers or wagons the minimum separation distance between the nearest parts of each group is shown in column 3.) The regulations must be consulted for full details. Loading and stowage requirements, including the sealing of closed containers to prevent unauthorized access, and the need to complete journeys and unloading as quickly as practicable. Carriage on passenger trains is restricted.

Security measures.

**Table 15.7 Limits on quantities of explosives permitted for carriage by rail in containers and wagons, and separation distances**

| <i>Column 1</i><br><i>Type of explosive</i> | <i>Column 2</i><br><i>Maximum net explosive content in tonnes in any group of adjacent containers or wagons</i> | <i>Column 3</i><br><i>Minimum separation distance in metres between groups of containers or wagons</i> |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| 1.1                                         | 40                                                                                                              | 80                                                                                                     |
| Any combination of 1.1, 1.3 and 1.5         | 40 (Aggregate)                                                                                                  | 80                                                                                                     |
| 1.3 and 1.5 alone or mixed                  | 120                                                                                                             | 40                                                                                                     |

### ***Radioactive substances***

UK regulations for the transport of radioactive materials set out the requirements for packaging, labelling and carriage of radioactive material including special forms of radioactive substances, and different types of package and their testing. Documentation requirements are set out together with advice on calculating maximum permissible radiation levels for packages of individual radionuclides and mixtures thereof. For excepted packages of limited activity the radiation level at any point on the external surface of the package must not exceed 5 Sv/h. Material which is not enclosed in, or forming a component part of, an instrument or manufactured article, may be transported in an excepted package if the activity of the material does not exceed the limit given in column 4 of Table 15.8.

**Table 15.8 Activity limits for excepted packages (except mixtures of radionuclides)\***

| <i>Column 1</i><br><i>Physical state of contents</i> | <i>Column 2</i><br><i>Instruments and articles<br/>Item limits</i> | <i>Column 3</i><br><i>Instruments and articles<br/>Package limits</i> | <i>Column 4</i><br><i>Materials<br/>Package</i> |
|------------------------------------------------------|--------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------------|
| Solids                                               |                                                                    |                                                                       |                                                 |
| Special form                                         | $10^{-2} A_1$                                                      | $A_1$                                                                 | $10^{-3} A_1$                                   |
| Other forms                                          | $10^{-2} A_2$                                                      | $A_2$                                                                 | $10^{-3} A_2$                                   |
| Liquids                                              | $10^{-3} A_2$                                                      | $10^{-1} A_2$                                                         | $10^{-4} A_2$                                   |
| Gases                                                |                                                                    |                                                                       |                                                 |
| Tritium                                              | $2 \times 10^{-2} A_2$                                             | $2 \times 10^{-1} A_2$                                                | $2 \times 10^{-2} A_2$                          |
| Special form                                         | $10^{-3} A_1$                                                      | $10^{-2} A_1$                                                         | $10^{-3} A_1$                                   |
| Other forms                                          | $10^{-3} A_2$                                                      | $10^{-2} A_2$                                                         | $10^{-3} A_2$                                   |

\* Values of  $A_1$  and  $A_2$  are given in the regulations for individual radionuclides (SI 1996 No. 1350).

## **Air transport**

### ***Dangerous substances***

Air freighting of hazardous chemicals must comply with the IATA Dangerous Goods Regulations, based on the International Civil Aviation Organization. The regulations address packaging, marking

and labelling, documentation, and handling arrangements. A section is devoted to radioactive materials. Detailed lists of individual articles and substances are included with their UN Classification, viz. explosives, gases, flammable liquids, flammable solids, oxidizing substances and organic peroxides, toxic and infectious substances, radioactive material, corrosives, and miscellaneous dangerous goods. Dangerous goods are assigned to the relevant packing group to reflect the degree of hazard they pose, viz.:

|                   |               |
|-------------------|---------------|
| Packing Group I   | Great danger  |
| Packing Group II  | Medium danger |
| Packing Group III | Minor danger  |

### ***Explosive substances***

Some classes of chemicals have been identified as too hazardous to be carried on aircraft under any conditions (Table 15.12). This includes the individual substances listed in Table 15.9. Other explosive materials have been forbidden under normal circumstances but may be carried with specific approval. Some are restricted to transport on cargo aircraft only but most can be transported on passenger aircraft provided certain requirements are met and the quantity is limited, e.g. the maximum net quantity of dangerous goods in inner packaging must be limited to that in Table 15.10. The regulations should be consulted for detailed advice. Both shippers and operators have responsibility to ensure the cargo is safe. Training is crucial in maintaining a safe regime; the minimum training requirements are summarized in Table 15.11.

## **Sea transport**

### ***Dangerous substances***

In addition to a myriad of general safety maritime legislation (e.g. in the UK the Merchant Shipping (International Safety Management (ISM) Code) Regulations 1998; the Docks Regulations 1988; the Freight Containers (Safety Convention) Regulations 1984; the Merchant Shipping (Carriage of Cargoes) Regulations 1999) there is a raft of more specific regulations governing the carriage of hazardous chemicals at sea. Examples include the Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations 1997; the Explosives in Harbour Areas Regulations (Northern Ireland) 1995; and the Dangerous Substances in Harbour Areas Regulations 1987, plus international requirements and codes.

Those at risk from packaged hazardous goods inside a transport unit include packers/unpackers, land users, stevedores, customs officials, ships' crews, and passengers. Simple guidance for packers and drivers of transport units containing dangerous goods is given in Table 15.13.

Ships and their cargoes are subjected to stresses in all directions during handling, transfer, and the journey. Adequate stowage is crucial. In line with the transportation of chemicals on land systems to address include:

- Strength, integrity, labelling and marking of individual packages.
- Selection of appropriate container.
- Safe loading packages into the containing unit.
- Adequate securing of packages within the unit.

**Table 15.9 Dangerous goods forbidden in aircraft under any circumstances (IATA)**

Acetyl cyclohexanesulfonyl peroxide, more than 82%, wetted with less than 12% water

Acetylene (liquefied)

Acetylene silver nitrate

Acetone cyanohydrin, stabilized

Allyl chloroformate

Allyl isothiocyanate, inhibited

Aluminium dross, wet or hot

Ammonium azide

Ammonium bromate

Ammonium chlorate

Ammonium fulminate

Ammonium nitrite

Ammonium permanganate

Antimony sulphide and a chlorate, mixtures of

Arsenic sulphide and a chlorate, mixtures of

Arsenic trichloride

Ascaridole

Azaurolic acid (salt of), (dry)

Azidodithiocarbonic acid

Azidoethyl nitrate

Azido guanidine picrate (dry)

5-Azido-1-hydroxy tetrazole

Azido hydroxy tetrazole (mercury and silver salts)

3-Azido-1,2-propylene glycol dinitrate

Azotetrazole (dry)

Benzene diazonium chloride (dry)

Benzene diazonium nitrate (dry)

Benzene triozone

Benzoxidiazoles (dry)

Benzoyl azide

Biphenyl triozone

Boron tribromide

Bromine azide

Bromine solutions

4-Bromo-1,2-dinitrobenzene

Bromosilane

1,2,4-Butanetriol trinitrate

tert-Butoxycarbonyl azide

*n*-Butyl chloroformate

tert-Butyl hydroperoxide, >90% with water

*n*-Butyl isocyanate

tert-Butyl isocyanate

tert-Butyl peroxyacetate, >76% in solution

tert-Butyl peroxyisobutyrate, >77% in solution

Charcoal screenings, wet

Charcoal, wet

Chlorine azide

Chlorine dioxide

Chloroacetaldehyde

Chloroacetone (unstabilized)

Chloroacetonitrile

Chloroformates, n.o.s.

Chloroprene, uninhibited

Chlorosulphonic acid

Coal briquettes, hot

Coke, hot

Copper acetylide

Table 15.9 Cont'd

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|                                                                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Copper amine azide                                                                                                                                         |
| Copper tetramine nitrate                                                                                                                                   |
| Crotonaldehyde, stabilized                                                                                                                                 |
| Cyanogen bromide                                                                                                                                           |
| Cyanuric triazide                                                                                                                                          |
| Cyclotetramethylenetetranitramine (dry or unphlegmatized) (HMX)                                                                                            |
| Diacetone alcohol peroxides, >57% in solution with >9% hydrogen peroxide, <26% diacetone alcohol and <9% water; total active oxygen content >10% by weight |
| <i>p</i> -Diazidobenzene                                                                                                                                   |
| 1,2-Diazoethane                                                                                                                                            |
| 1,1'-Diazoaminonaphthalene                                                                                                                                 |
| Diazoaminotetrazole (dry)                                                                                                                                  |
| Diazodinitrophenol (dry)                                                                                                                                   |
| Diazodiphenylmethane                                                                                                                                       |
| 2-Diazo-1-naphthol-4-sulphochloride                                                                                                                        |
| 2-Diazo-1-naphthol-5-sulphochloride                                                                                                                        |
| Diazonium nitrates (dry)                                                                                                                                   |
| Diazonium perchlorates (dry)                                                                                                                               |
| 1,3-Diazopropane                                                                                                                                           |
| Dibenzyl peroxydicarbonate, >87% with water                                                                                                                |
| Dibromoacetylene                                                                                                                                           |
| 2,2-Di-(tert-butylperoxy) butane, >55% in solution                                                                                                         |
| Di- <i>n</i> -butyl peroxydicarbonate, >52% in solution                                                                                                    |
| Di-(tert-butylperoxy) phthalate, >55% in solution                                                                                                          |
| Dichloroacetylene                                                                                                                                          |
| N,N'-Dichlorazodicarbonamidine (salts of), (dry)                                                                                                           |
| Dichloroethyl sulphide                                                                                                                                     |
| Dichlorovinylchloroarsine                                                                                                                                  |
| 2,2-Di-(4,4-di-tert-butylperoxycyclohexyl) propane, >42% with inert solid                                                                                  |
| Di-2,4-dichlorobenzoyl peroxide, >75% with water                                                                                                           |
| Diethanol nitrosamine dinitrate (dry)                                                                                                                      |
| Diethyleneglycol dinitrate (dry)                                                                                                                           |
| Diethylgold bromide                                                                                                                                        |
| Diethyl peroxydicarbonate, >27% in solution                                                                                                                |
| 1,8-Dihydroxy-2,4,5,7-tetranitroanthraquinone (chrysamminic acid)                                                                                          |
| Di-(1-hydroxytetrazole) (dry)                                                                                                                              |
| Diiodoacetylene                                                                                                                                            |
| 2,5-Dimethyl-2,5-dihydroperoxy hexane, >82% with water                                                                                                     |
| Dimethylhexane dihydroperoxide, >82% with water                                                                                                            |
| Di-(1-naphthoyl) peroxide                                                                                                                                  |
| Dinitro-7,8-dimethylglycoluril (dry)                                                                                                                       |
| 1,3-Dinitro-5,5-dimethyl hydantoin                                                                                                                         |
| 1,3-Dinitro-4,5-dinitrosobenzene                                                                                                                           |
| 1,1-Dinitroethane (dry)                                                                                                                                    |
| 1,2-Dinitroethane                                                                                                                                          |
| Dinitroglycoluril                                                                                                                                          |
| Dinitromethane                                                                                                                                             |
| Dinitropropylene glycol                                                                                                                                    |
| 2,4-Dinitroresorcinol (heavy metal salts of) (dry)                                                                                                         |
| 4,6-Dinitroresorcinol (heavy metal salts of), (dry)                                                                                                        |
| 3,5-Dinitrosalicylic acid (lead salt), (dry)                                                                                                               |
| Dinitrosobenzylamidine and salts of (dry)                                                                                                                  |
| 2,2-Dinitrostilbene                                                                                                                                        |
| 1,4-Dinitro-1,1,4,4-tetramethylolbutanetetranitrate (dry)                                                                                                  |
| 2,4-Dinitro-1,3,5-trimethylbenzene                                                                                                                         |
| Di-( $\beta$ -nitroxyethyl) ammonium nitrate                                                                                                               |
| $\alpha$ , $\alpha'$ -Di-(nitroxyl) methylether                                                                                                            |
| 1,9-Dinitroxyl pentamethylene-2,4,6,8-tetramine (dry)                                                                                                      |
| Dipropionyl peroxide, >28% in solution                                                                                                                     |

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**Table 15.9 Cont'd**


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|                                                            |
|------------------------------------------------------------|
| Ethanol amine dinitrate                                    |
| Ethylene diamine diperchlorate                             |
| Ethylene glycol dinitrate                                  |
| Ethyl hydroperoxide                                        |
| Ethyl nitrate                                              |
| Ethyl nitrite                                              |
| Ethyl perchlorate                                          |
| <br>                                                       |
| Fulminate of mercury (dry)                                 |
| Fulminating gold                                           |
| Fulminating mercury                                        |
| Fulminating platinum                                       |
| Fulminating silver                                         |
| Fulminic acid                                              |
| <br>                                                       |
| Galactosan trinitrate                                      |
| Glycerol-1,3-dinitrate                                     |
| Glycerol gluconate trinitrate                              |
| Glycerol lactate trinitrate                                |
| Guanyl nitrosaminoguanylidene hydrazine (dry)              |
| Guanyl nitrosaminoguanyltetrazene                          |
| <br>                                                       |
| Hexamethylene triperoxide diamine (dry)                    |
| Hexamethylol benzene hexanitrate                           |
| Hexanitroazoxy benzene                                     |
| 2,2',4,4',6,6'-Hexanitro-3,3'-dihydroxyazobenzene (dry)    |
| N,N'-(hexanitrodiphenyl) ethylene dinitramine (dry)        |
| 2,3', 4,4',6,6'-Hexanitrodiphenylether                     |
| Hexanitrodiphenyl urea                                     |
| Hexanitroethane                                            |
| Hexanitrooxanilide                                         |
| HMX (dry or unphlegmatized)                                |
| Hydrazine azide                                            |
| Hydrazine chlorate                                         |
| Hydrazine dicarbonic acid diazide                          |
| Hydrazine perchlorate                                      |
| Hydrazine selenate                                         |
| Hydrogen cyanide, unstabilized                             |
| Hydroxyl amine iodide                                      |
| Hyponitrous acid                                           |
| <br>                                                       |
| Ignition element for lighter, containing pyrophoric liquid |
| Inositol hexanitrate (dry)                                 |
| Inulin trinitrate (dry)                                    |
| Iodine azide (dry)                                         |
| Iodoxy compounds (dry)                                     |
| Iridium nitratopentamine iridium nitrate                   |
| Isopropylcumyl hydroperoxide, >72% in solution             |
| Isothiocyanic acid                                         |
| <br>                                                       |
| Lead azide (dry)                                           |
| Lead nitroresorcinate (dry)                                |
| Lead picrate (dry)                                         |
| Lead styphnate (dry)                                       |
| Lead trinitroresorcinate (dry)                             |
| Lighters (cigarettes) containing pyrophoric liquid         |
| Lighters (cigarettes) with lighter fluids                  |

Table 15.9 Cont'd

Magnesium dross, wet or hot  
 Mannitan tetranitrate  
 Mannitol hexanitate (dry)  
 Mercurous azide  
 Mercury acetylide  
 Mercury iodide aquabasic ammonobasic (Iodide of Millon's base)  
 Mercury nitride  
 Methazoic acid  
 Methylamine dinitramine and dry salts thereof  
 Methylamine nitroform  
 Methylamine perchlorate (dry)  
 Methylchloroarsine  
 Methylene glycol dinitrate  
 Methyl ethyl ketone peroxide, >50%  
 alpha-Methylglucoside tetranitrate  
 alpha-Methylglycerol trinitrate  
 Methyl nitramine (dry) metal salts of  
 Methyl nitrate  
 Methyl nitrite  
 Methyl picric acid (heavy metal salts of)  
 Methyl trimethylol methane trinitrate

Naphthalene diozonide  
 Naphthyl amineperchlorate  
 Nickel picrate  
 Nitrates of diazonium compounds  
*N*-Nitroaniline  
*m*-Nitrobenzene diazonium perchlorate  
 6-Nitro-4-diazotoluene-3-sulphonic acid (dry)  
 Nitroethyl nitrate  
 Nitroethylene polymer  
 Nitrogen trichloride  
 Nitrogen triiodide  
 Nitrogen triiodide monoamine  
 Nitroglycerin, liquid, not desensitized  
 Nitroguanidine nitrate  
 1-Nitro hydantoin  
 Nitro isobutane triol trinitrate  
 Nitromannite (dry)  
 Nitromethane  
*N*-Nitro-*N*-methylglycolamide nitrate  
 2-Nitro-2-methylpropanol nitrate  
*m*-Nitrophenyldinitro methane  
 Nitrosugars (dry)

1,7-Octadiene-3,5-diyne-1,8-dimethoxy-9-octadecynoic acid  
 Octogen (dry)

Pentaerythrite tetranitrate (dry)  
 Pentaerythritol tetranitrate (dry)  
 Pentanitroaniline (dry)  
 Perchloric acid >72% strength  
 Peroxyacetic acid, >43% and with >6% hydrogen peroxide  
 PETN (dry)  
*m*-Phenylene diaminediperchlorate (dry)  
 Phosphorus (white or red) and a chlorate, mixtures of  
 Potassium carbonyl  
 Pyridine perchlorate

**Table 15.9 Cont'd**

Quebrachitol pentanitrite

Security type attaché cases incorporating lithium batteries and/or pyrotechnic material

Selenium nitride

Silver acetylide (dry)

Silver azide (dry)

Silver chlorite (dry)

Silver fulminate (dry)

Silver oxalate (dry)

Silver picrate (dry)

Sodium picryl peroxide

Sodium tetranitride

Sucrose octanitate (dry)

Tetraazido benzene quinone

Tetraethylammonium perchlorate (dry)

Tetramethylene diperoxide dicarbamide

Tetranitro diglycerin

2,3,4,6-Tetranitrophenol

2,3,4,6-Tetranitrophenyl methyl nitramine

2,3,4,6-Tetranitrophenylnitramine

Tetranitroresorcinol (dry)

2,3,5,6-Tetranitroso-1,4-dinitrobenzene

2,3,5,6-Tetranitroso nitrobenzene (dry)

Tetrazene (dry)

Tetrazine

Tetrazolyl azide (dry)

Thionyl chloride

Thiophosgene

Titanium tetrachloride

Trichloromethyl perchlorate

Triformoxime trinitrate

Trimethylacetyl chloride

Trimethylene glycol diperchlorate

Trimethylol nitromethane trinitrate

1,3,5-Trimethyl-2,4,6-trinitrobenzene

Trinitroacetic acid

Trinitroacetone nitrile

Trinitroamine cobalt

2,4,6-Trinitro-1,3-diazobenzene

Trinitroethanol

Trinitroethylnitrate

Trinitromethane

2,4,6-Trinitrophenyl guanidine (dry)

2,4,6-Trinitrophenyl nitramine

2,4,6-Trinitrophenyl trimethylol methyl nitramine trinitrate (dry)

2,4,6-Trinitroso-3-methyl nitraminoanisole

Trinitrotetramine cobalt nitrate

2,4,6-Trinitro-1,3,5-triazido benzene (dry)

Tri-( $\beta$ -nitroxyethyl) ammonium nitrate

Tris, bis-bifluoroamino diethoxy propane (TVOPA)

Vinyl nitrate polymer

p-Xylyl diazide

**Table 15.10 Quantity limits of dangerous goods accepted in small amounts for transport by air**

| <i>Packing group of the substance</i>                              | <i>Packing group I</i>  |                    | <i>Packing group II</i> |                    | <i>Packing group III</i> |                |
|--------------------------------------------------------------------|-------------------------|--------------------|-------------------------|--------------------|--------------------------|----------------|
| <i>Class or division or primary or subsidiary risk<sup>a</sup></i> | <i>Packagings Inner</i> | <i>Outer</i>       | <i>Packagings Inner</i> | <i>Outer</i>       | <i>Packagings Inner</i>  | <i>Outer</i>   |
| 1: Explosives                                                      |                         |                    | Forbidden               |                    |                          |                |
| 2.1: Flammable gas                                                 |                         |                    | Forbidden               |                    |                          |                |
| 2.2: Non-Flammable, non-toxic gas                                  |                         |                    | See Note <sup>b</sup>   |                    |                          |                |
| 2.3: Toxic gas                                                     |                         |                    | Forbidden               |                    |                          |                |
| 3: Flammable liquid                                                | 30 ml                   | 300 ml             | 30 ml                   | 500 ml             | 30 ml                    | 1 l            |
| 4.1: Self reactive substances                                      |                         |                    | Forbidden               |                    |                          |                |
| 4.1: Other flammable solids                                        | Forbidden               |                    | 30 g                    | 500 g              | 30 g                     | 1 kg           |
| 4.2: Pyrophoric substances                                         | Forbidden               |                    | Not Applicable          |                    | Not Applicable           |                |
| 4.2: Spontaneously combustible substances                          | Not Applicable          |                    | 30 g                    | 500 g              | 30 g                     | 1 kg           |
| 4.3: Water reactive substances                                     | Forbidden               |                    | 30 g or<br>30 ml        | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 5.1: Oxidizers                                                     | Forbidden               |                    | 30 g or<br>30 ml        | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 5.2: Organic peroxides <sup>c</sup>                                | Not applicable          |                    | 30 g or<br>30 ml        | 500 g or<br>500 ml | Not Applicable           |                |
| 6.1: Toxic substances – inhalation                                 | Forbidden               |                    | 1 g or<br>1 ml          | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 6.1: Toxic substances – oral                                       | 1 g or<br>1 ml          | 300 g or<br>300 ml | 1 g or<br>1 ml          | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 6.1: Toxic substances – dermal                                     | 1 g or<br>1 ml          | 300 g or<br>300 ml | 1 g or<br>1 ml          | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 6.2: Infectious substances                                         |                         |                    | Forbidden               |                    |                          |                |
| 7: Radioactive material <sup>d</sup>                               |                         |                    | Forbidden               |                    |                          |                |
| 8: Corrosive materials <sup>e</sup>                                | Forbidden               |                    | 30 g or<br>30 ml        | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |
| 9: Magnetized materials                                            |                         |                    | Forbidden               |                    |                          |                |
| 9: Other miscellaneous materials <sup>f</sup>                      | Not Applicable          |                    | 30 g or<br>30 ml        | 500 g or<br>500 ml | 30 g or<br>30 ml         | 1 kg or<br>1 l |

<sup>a</sup> The more restrictive quantity required by either the Primary or Subsidiary Risk must be used.

<sup>b</sup> For inner packagings, the quantity contained in receptacle with a water capacity of 30 ml. For outer packagings, the sum of the water capacities of all the inner packagings contained must not exceed 1 litre.

<sup>c</sup> Applies only to Organic Peroxides when contained in a chemical kit or a first-aid kit.

<sup>d</sup> See 10.5.9.8.1, 10.5.9.8.2 and 10.5.9.7, radioactive material in excepted packages.

<sup>e</sup> UN 2803 and UN 2809 are not permitted in Excepted Quantities.

<sup>f</sup> For substances in Class 9 for which no packing group is indicated in the List of Dangerous Goods, Packing Group II quantities must be used.

**Table 15.11 Minimum training requirements for staff engaged in the transport of hazardous chemicals by air**

| Relevant aspect with which staff should be familiar,<br>as a minimum | Type of staff |   |   |   |   |   |   |   |
|----------------------------------------------------------------------|---------------|---|---|---|---|---|---|---|
|                                                                      | A             | B | C | D | E | F | G | H |
| General philosophy                                                   | x             | x | x | x | x | x | x | x |
| Limitations                                                          | x             |   | x |   | x | x | x | x |
| General requirements                                                 | x             |   | x |   |   | x |   |   |
| Classification                                                       | x             | x | x |   |   | x |   |   |
| List of dangerous goods                                              | x             | x | x |   |   | x | x |   |
| General packing requirements                                         | x             | x | x |   |   | x |   |   |
| Packing instructions                                                 | x             | x | x |   |   | x |   |   |
| Labelling and marking                                                | x             | x | x | x | x | x | x | x |
| Shipper's declaration and other documentation                        | x             |   | x |   |   | x |   |   |
| Acceptance procedures                                                |               |   | x |   |   |   |   |   |
| Storage and loading procedures                                       |               |   | x | x |   |   | x |   |
| Pilot's notification                                                 |               |   | x | x |   |   | x |   |
| Provisions for passengers and crew                                   |               |   |   | x | x |   | x | x |
| Emergency procedures                                                 |               |   | x | x |   |   | x | x |

**Staff category**

- A Shippers, shipper's agents including operator's staff acting as shippers, operator's staff preparing dangerous goods
- B Packers
- C Cargo acceptance staff of operators and agencies acting on behalf of operators
- D Staff of operators and agencies acting on behalf of operators engaged in the ground handling, storage and loading of cargo and baggage
- E Passenger handling staff and security staff who deal with the screening of passengers and their baggage
- F Staff of agencies other than operators involved in processing cargo
- G Flight crew members
- H Crew members (other than flight crew)

Depending upon responsibilities the training requirements will alter, e.g. if an operator carries only cargo those aspects pertaining to passengers may be omitted for his staff and flight crew.

**Table 15.12 Classes of dangerous goods forbidden for transport by air**

Explosives which ignite or decompose when subjected to a temperature of 75 °C for 48 hours.

Explosives containing both chlorates and ammonium salts.

Explosives containing mixtures of chlorates with phosphorus.

Solid explosives which are classified as extremely sensitive to mechanical shock.

Liquid explosives which are classified as moderately sensitive to mechanical shock.

Any substance, as presented for transport, which is liable to produce a dangerous evolution of heat or gas under the conditions normally encountered in air transport.

Flammable solids and organic peroxides having, as tested, explosive properties and which are packed in such a way that the classification procedure would require the use of an explosives label as a subsidiary risk label.

Dangerous goods listed in Table 15.9

Provision of relevant documentation/information, e.g. for packers, haulier, shipper, etc. For example, the ship's owner must be provided with:

- the container packing certificate/vehicle declaration;
- a signed dangerous goods declaration; and/or
- a marine pollution declaration.

A checklist summarizing the range of responsibilities is given in Table 15.14.

Hazardous substances in ports are governed by the Dangerous Substances in Harbour Areas Regulations 1987. These provide for:

**Table 15.13 Guidance relating to dangerous goods in cargo transport units (CTU) for transport by sea**

|               | <i>Packer</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <i>Driver</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Do</b>     | Check individual packages for damage, leaks, etc.<br>Check packages show:<br>proper shipping name;<br>UN number;<br>class label;<br>subsidiary risk label (where relevant);<br>marine pollutant mark (where relevant);<br>UN type approval mark<br>Confirm nature of hazards from labels<br>Visual check on condition of CTU before loading<br>Check validity of safety approval plate of freight container<br>Removal of irrelevant placards<br>Follow loading plan when packing CTU<br>Secure and brace packages inside CTU<br>Securely close and seal CTU when loading is complete<br>Ensure container packing certificate/vehicle declaration signed and forwarded to ship operator or master<br>Ensure placards are present on sides and ends of CTU<br>Ensure written information on potential hazards is passed from shipper to haulier | Check that goods and quantities are on dangerous goods declaration<br>Obtain from packer the container packing certificate/vehicle declaration<br>Obtain and carry transport documentation including TREMCARD, etc.<br>Check that any freight container has valid safety approval plate<br>Visually check the outside of the CTU for damage, etc.<br>Ensure CTU doors are properly secured<br>Learn emergency procedures<br>Ensure availability of appropriate personal protective equipment as advised in transport documentation, and suitable fire extinguisher<br>Check sides and ends of CTU are placarded appropriately<br>Ensure irrelevant hazard data are removed<br>Ensure controls against fire and explosion are taken during the journey<br>When parking vehicle avoid creating risk to local people |
| <b>Do not</b> | Handle damaged, leaking or stained packages<br>Load a freight container without valid safety approval plate<br>Load packages of dangerous goods which are improperly labelled and marked<br>Load packages into a dirty, wet or damaged CTU<br>Place packages in a CTU with incorrect placards still visible<br>Attempt to load packages without loading plan to ensure segregation of incompatibles<br>Leave cargo in an insecure CTU<br>Exceed the maximum gross mass of the CTU                                                                                                                                                                                                                                                                                                                                                              | Accept load or start journey without relevant hazard information from shipper<br>Accept freight container without valid safety approval plate<br>Allow CTU to travel with irrelevant hazard placards, marks or signs or if lacking in information<br>Allow placards to become obscured or damaged<br>Have irrelevant hazard warning information in the cab<br>Start journey without checking availability of safety equipment in suitable condition for use<br>Smoke or use other means of ignition<br>Carry unauthorized passengers                                                                                                                                                                                                                                                                              |

Entry of dangerous substances into harbours.

Marking and navigation.

Handling of dangerous substances.

Liquid dangerous substances.

Packaging and labelling.

Emergency arrangements and untoward incidents.

Storage of dangerous substances.

Explosives.

Ship/shore checklist.

Information on dangerous chemicals entering harbour areas from sea should be provided to the harbour master by the ship's master. Notification should also include the ship's name, call sign,

**Table 15.14 Checklist of responsibilities for sea transportation of chemicals**

| <i>Action</i>                                                           | <i>Person responsible</i>                                                          |
|-------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| Dangerous chemical properly packaged and labelled                       | Manufacturer/supplier/shipper                                                      |
| Training and supervision of those packing                               | Packer                                                                             |
| Health and safety of packers                                            | Packer                                                                             |
| Construction, maintenance and plating of freight container              | Owner or lessee of container or others who use or permit use, e.g. packer, haulier |
| Visual inspection of container and packages                             | Packer                                                                             |
| Container and vehicle loading – all packages securely stowed and braced | Packer                                                                             |
| Provision of signed container/packing certificate – vehicle declaration | Packer                                                                             |
| Placarding of cargo transport unit                                      | Packer or shipper                                                                  |
| Placarding of vehicle                                                   | Haulier                                                                            |
| Provision of signed dangerous goods declaration                         | Shipper                                                                            |
| Information of hazards to haulier                                       | Shipper                                                                            |
| Advanced notification to port                                           | Haulier                                                                            |
| Safety during transfer of dangerous goods by road                       | Haulier/driver                                                                     |

nationality, overall length, draught and beam, intended destination within the harbour, and estimated time of arrival. In addition, for marine tankers of 1600 tonnes gross, or carrying certain chemicals and gases or oil in bulk, the following information should be provided:

- nature and quantity of chemicals, gas or oil carried by the vessel;
- whether tanker is fitted with operational inert gas system;
- whether atmosphere of cargo tanks has been rendered non-flammable;
- information about tanker certificates;
- defects to hull, machinery or equipment which may affect safe manoeuvrability of ship, affect safety of other vessels, constitute a marine environment hazard;
- whether there is a hazard to property or people near to the harbour.

Controls for the safe transfer of chemicals between ship and shore will vary in detail. The escape of dust and vapour should be minimized when loading and unloading of bulk liquids or solids and persons should not be at risk. Precautions to avoid contact with water are needed when transferring water-incompatible materials (page 229). Precautions for handling explosives include:

- packages should be kept from berth until vessel/vehicle is ready to receive them;
- where necessary restrict the handling to a no-smoking secure area;
- warning signs should be displayed during the handling process;
- vehicle interiors should be clean;
- metal-free shoes should be used;
- radio transmitters should be banned within 50 metres during the transfer, except for low-power (25 watt) radios in mobile equipment such as cranes with aerials outside 2 metres of the explosives.

Table 15.15 summarizes the precautions to be followed by the berth operator for the transfer of dangerous bulk liquids.

**Table 15.15 General precautions to be followed for the transfer of dangerous liquids in bulk\***

Pipelines/hoses should be properly designed, of adequate strength and of good construction, from sound and suitable material, properly maintained, appropriately protected against impact and used only for intended materials.

Area in vicinity of pipeline berth should be adequately ventilated.

Do not exceed safe working pressure; consider need for safety relief devices.

Pipelines for flammable liquids/gases to be protected against arcing during connection and disconnection, e.g. hose strings and metal arms fitted with insulating flange or a single length of non-conducting hose to ensure discontinuity between vessel and shore. Seaward pipework should be electrically continuous to vessel, and landward piping electrically continuous to the jetty earthing system.

Insulating flanges or single length non-conducting hose should not be short circuited with external metal.

Insulating flanges to be inspected and tested at intervals not exceeding one month to ensure the insulation is clean and in good condition. Resistance should be measured between the metal pipe on shore side of flange and the end of the hose or metal arm when freely suspended. The measured value should be at least 1000 ohms.

Cargo hoses with internal bonding between end flanges to be checked for electrical continuity before introduction into service and periodically thereafter.

Berth operator should possess a supplier's certificate for any hose forming part of the pipeline confirming that tests have shown it is unlikely to burst in service.

Hoses to be indelibly marked to indicate the substances for which it is intended, its safe working pressure, proof-test pressure, date tested, and maximum or minimum service temperature.

Before first use hoses to be inspected visually internally and externally and tested at proof pressure. Repeat at least annually and include check on electrical resistance. The resistance of the complete assembly should be not more than 15 ohms, unless the hose is intended to be non-conducting when resistance should be at least 25 000 ohms. Inspect hose daily when in use. Hoses used at monobuoys should also be hydraulically tested.

When rigged for use hoses should be under supervision.

After use drain before disconnection.

Close each end of hose until reconnected unless made safe by draining and purging.

Check any cargo handling controls, emergency shutdown and alarms are working before commencing transfer.

Prior to the transfer the berth operator and master should agree maximum loading or unloading rate. Berth operator to check periodically these are not exceeded.

Communication should be established and maintained between people on the ship, the berth and at the storage installation during loading/unloading.

Berth operator to take reasonably practicable steps to control flammable or toxic gas escapes (e.g. hose support, flange couplings liquid- or gas-tight, drip trays).

Unloading or loading liquefied gas escapes should be limited to those vented via safety devices or authorized by the harbour master. Rate of transfer should ensure pipelines cool gradually; lines should be vented safely at the end of the transfer.

Berth operator should ensure the unloading or loading of ship's stores does not endanger the transfer of dangerous chemicals or ballast water contaminated with dangerous substances, gas freeing, or tank cleaning.

At the completion of the transfer of dangerous liquids the berth operator should render pipework, valves and associated equipment safe; valves and tanks should be closed and shore pipeline blanked off.

\* The full SI 1987 No. 37 and Approved Code of Practice should be consulted for complete details.

## Modes of transport for liquids, gases and solids

### *Liquids*

Liquids may be transported in numerous ways depending upon the quantity and distance involved. The associated hazards are chemical-specific and also depend upon the physical condition, i.e.:

liquid at atmospheric pressure and ambient temperature;  
 liquefied gas under pressure and at ambient temperature; or  
 liquefied gas at atmospheric pressure and at low temperature (i.e. fully-refrigerated transport).

Flammable liquid which spreads can result, on ignition, in a running liquid fire. If spilled onto



water spreading will be more extensive, and vaporization will be more rapid, because of the increased rate of heat transfer. Unstable chemicals may pose an explosion risk. Toxic chemicals may be released as a liquid which spreads or as a vapour cloud. The risk of environmental damage is likely to be potentially serious in most cases.

The common means for transport are:

In bottles, plastic drums, steel or resin-lined drums (e.g. of 210 litre capacity).

Glass bottles which are used only for small quantities, e.g. 2.5 litres, but should be protected in specially designed carriers.

Plastic drums, which must not be subjected to excessive loading and, if returnable, require checking for degradation, e.g. due to cracking, impact, distortion.

By road or rail tanker.

By ship, e.g. crude petroleum.

By pipeline, e.g. LPG.

Accidents may be caused by impact, failure of container or pipeline, or during loading/unloading. The hazards arise from:

Fire and/or explosion.

Toxic release:

– of a conventional type; or

– of an ultratoxic; either instantaneous or prolonged.

Environmental pollution.

These mirror those at fixed installations, but loss of containment due to the triggering event can occur anywhere en route. Thus accidents may occur in populated or environmentally sensitive locations, or where domino effects are less easily controlled. Common risks are also associated with all vehicular movements and mechanical/manual loading/unloading activities.

Problems may arise with switch-loading of road tankers, ships or pipelines and with the use of returnable containers. The important considerations for safety are:

Compatibility of the chemical with the materials of construction.

Adequacy of cleaning out, and removal of residues from, the previous chemical carried to avoid cross-contamination and potential reactive hazards on refilling.

A sound information transfer system to avoid confusion of chemical identities and to ensure the specific risks of each load are identified and made known to the carrier/transporter.

Adequacy of decontamination of 'empty' containers, tankers, etc. before return.

## ***Gases***

Gases are transported:

Under pressure in cylinders or pressurized tanks subject to the Pressure Systems Safety Regulations 2000.

By pipeline.

In general, loss of containment is more serious than with the majority of liquids (unless they are in a superheated state) since atmospheric dispersion will be immediate.

Release of a flammable gas or vapour may result in a jet or flash fire or any type of vapour

cloud explosion (p. 178). In fire conditions there can be a BLEVE hazard from containers of liquefied gas. Release of a toxic gas or vapour always poses a potential risk of personal injury and possibly of environmental damage.

Whilst they will differ depending upon gas properties, the procedures and precautions appropriate for transport of cylinder gases are exemplified for LPG in Table 15.16.

**Table 15.16 Procedures for safe transport of LPG cylinders by road**

---

**Transport**

Carry cylinders on open vehicles. Keep cylinders upright and adequately secured, e.g. with a rope.  
 Keep a fire extinguisher, e.g. 1 kg dry power, in the cab to deal with any small fire, e.g. an engine fire.  
 Do not leave cylinders on vehicles unsupervised.  
 Ensure that the driver has received adequate training and instructions about the hazards of LPG, emergency procedures, driver duties, etc.  
 Ensure that relevant information is readily available on the vehicle, e.g. on a clipboard in the cab. This written information, e.g. as a TREMCARD, should contain details of the nature of the load and the action to take in an emergency.

**Duties of vehicle operator**

Check whether the Road Traffic (Carriage of Dangerous Packages, etc.) Regulations 1986 apply. Exceptions apply to cylinders <5 litres; cylinders which are part of equipment carried on the vehicles, e.g. burning gear, bitumen boilers; cylinders associated with vehicle operation, e.g. cooking, water heating.  
 Ensure the vehicle is suitable, normally an open vehicle. Use of a closed vehicle should be restricted to a small number of cylinders with a load compartment having adequate ventilation.  
 Ensure the driver has adequate information in writing, e.g. a TREMCARD.  
 Ensure the driver is provided with adequate instruction and training and keeps necessary records.  
 Ensure loading, stowage, unloading are performed safely. All cylinders should be packed, strapped, supported in frames, or loaded to avoid damage resulting from relative movement. Cylinders should be stowed with valves uppermost.  
 Ensure all precautions are taken to prevent fire or explosion.  
 Ensure suitable fire extinguishers are provided.  
 Ensure the vehicle displays two orange plates if 500 kg of LPG is carried.  
 Report any fire, uncontrolled release or escape of the LPG, to the appropriate authority.

**Duties of the driver**

Ensure the relevant written information from the operator is always available during carriage. Destroy, remove or lock-away information about previous loads.  
 Ensure loading, stowage and unloading are performed safely.  
 Ensure all precautions against fire or explosion are taken during carriage.  
 Display orange plates (when required) and keep them clean and free from obstruction.  
 If >3 tonnes of LPG is carried, when the vehicle is not being driven, ensure parking is in a safe place or that it is supervised (by the driver or a competent person aged >18).  
 On request provide appropriate information to persons authorized to inspect the vehicle and load.  
 Report any fire, uncontrolled release or escape of LPG, to the operator.

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The integrity of pipelines depends upon correct design, including materials selection, support and protection from mechanical damage. Depending upon the gas, routine inspection and maintenance may be supplemented by the provision of gas detection and alarm systems. Other considerations are exemplified by the safety-related controls on the transportation of domestic gas via pipeline systems summarized in Table 15.17.

## **Solids**

A wide variety of containers of differing capacity and design are used for solids transport, i.e. fibreboard, metal, resin-lined metal, plastic drums; plastic, paper or hessian sacks; tote bins; bulk tanker; lorry-load. The material may then be stored in the containers as received, in hoppers or silos, or simply in piles depending upon its properties and value.

**Table 15.17 Measures for the control of management of domestic gas through pipeline systems (the Gas Safety (Management) Regulations 1996)**

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**Safety case – gas transporter**

- Day-to-day management to ensure continuity of gas supply at the correct pressure and composition.
- Arrangement to deal with reports of gas leaks and suspected CO emissions.
- Arrangements for investigation of fire and explosion incidents.

**Safety case – network emergency controller**

- Arrangements to monitor the network – to identify any potential national gas supply emergency and to coordinate preventive action.
  - Arrangements to direct transporters to reduce consumption if it is impossible to prevent a gas emergency developing.
  - Procedures for the safe restoration of gas supply following an emergency.
  - Arrangements for emergency services.
- 

Bulk transport is often favoured since it reduces the requirement for manual handling and facilitates enclosed transfer into storage, thus reducing risks at the customer's factory. Stock inventories may, however, be increased.

Special considerations arise in the transport of:

unstable chemicals (p. 235)

chemicals prone to self-heating (p. 214). These may involve:

- breakdown of stock into numerous smaller units;
- blanketing of the material (e.g. to prevent ingress of air to oxidizable material or complete quenching, e.g. with water);
- regular temperature measurements;

reactive chemicals (p. 228). Segregation from incompatible chemicals is essential (p. 233)

chemicals prone to generate combustible dust clouds (p. 220).

## Loading and unloading

### *Tankers*

Accidents during the loading/unloading of chemicals into/from road tankers, railway tankers, ships and barges may involve discharge of the wrong chemical, vehicle movement during transfer, failure of, or damage to, flexible transfer hoses, disconnection of transfer hoses whilst still under pressure, and overfilling. Loading/unloading should be in designated areas positioned at an appropriate distance from public roads, occupied buildings and – if relevant – possible ignition sources. A good level of ventilation should be ensured together with spillage control facilities. These should be backed up by standard operating procedures.

A basic safety audit covering design and system of work features to be covered for the loading/unloading of non-pressurized hazardous liquids to/from tankers or tank containers is given in Table 15.18.

**Table 15.18 Basic safety audit checklist for loading/unloading non-pressurised hazardous liquids; tankers or tank containers****Site**

Are there adequate signs available at the site entrance to direct the traffic to the appropriate loading or off-loading point?  
 Is there adequate access to the loading area?  
 Where, and to whom, does the driver report?  
 Is there a dedicated waiting area for the tanker?  
 Are there 'no smoking' notices where appropriate?

**Tanker bay**

Can the vehicles drive in and out without reversing?  
 Check separation distances from equipment, buildings, other activities, etc.  
 Does the ground slope? Check potential vehicle run-away.  
 Check venting and ventilation facilities.  
 Is vapour recovery provided?  
 Are there notices for action in an emergency (e.g. in the event of spillage, do not attempt to drive away)?  
 Is the lighting adequate? Is there back-up?  
 Will spillages be contained?  
 Would fire water be contained?  
 Earthing provisions.

**Tanker or tank container**

Is it a dedicated tanker or tank container?  
 Who provides the pump and hoses and are these checked (integrity, compatibility)?  
 How is the tanker filled – top or bottom?  
 Are appropriate connections available (flanged, snap-on, self-sealing)?  
 Check lids, pressure and vacuum relief.  
 Is switch loading in operation? If so, have the hazards been recognized?  
 Is tank dipping still necessary?  
 Is the tanker labelled correctly?  
 Check for cleanliness of tanker if loading.

**Product**

Check hazards of substance (e.g. reactivity, flammability, toxicity, corrosivity, etc.) versus precautions.  
 Check need for purging and inerting.  
 Check COSHH regulations compliance.  
 Check for provision of safety data sheet with paperwork.  
 Are quality control provisions adequate?

**Activities**

Correct, identified tank.  
 Are up-to-date operating instructions available?  
 What are the tanker driver's responsibilities?  
 Check paperwork provided versus correct material and quantities. Delay if unconfirmed.  
 Is a tanker run-away or drive-away protective system used?  
 Check p.p.e. needs.  
 Who has ultimate responsibility for rail cars, site management or the train driver?

**Connection**

Earthing and bonding procedure.

Approval to connect.

Check provision of appropriate loading arms, connections, couplings.  
 Is access available to tanker top for connections or operation of hatches?  
 Are guard rails or safety harnesses provided for tanker top operations?

**Loading/unloading**

Area cordoned off; restricted access.  
 Quantities and levels (adequacy of).  
 No simultaneous transfers.  
 Is overfilling alarm and protection provided?  
 Metering; calibration and reliability.  
 Velocity of liquid in pipes versus static electricity hazards.  
 Vapour venting and gas balancing.  
 If vapour return is used, what pressure is required and is it below the tanker relief valve setting?  
 Loading hot liquids; temperature checks, line heating and insulation.  
 Procedure for blockages (and disposal of residues).

**Safety and general management**

Timing of loading/unloading.  
 The management policy for inclusion of safety, health and environment.  
 A direct statement of the responsibility for the loading and unloading operation.  
 Driver training and licence check.  
 Operator training check.  
 Need for barriers, chocks or brake interlocks.  
 Drains and handling spillages.  
 Other safety equipment.  
 Control of ignition sources.  
 Smoking policy and notices.  
 Means of escape.  
 Reporting of faults and incidents.

**Disconnection**

Ensure lines clear and depressurized.  
 Approvals.  
 Spillages, containment and treatment.

**Checking**

Product specification and sampling.  
 Hoses, pumps, connections, lids, locked or capped valves, compartments.  
 Contamination and cross-contamination.  
 Quantities, weights or levels.  
 Actions in the event of faults.  
 Is the vehicle suitable for the material and in a roadworthy condition before loading?

**Vehicle departure**

Tanker exterior cleaning?  
 Security of openings, connections and valves.  
 Procedure on overfilling.  
 Approvals and paperwork. Complete documentation.

Table 15.18 Cont'd

|                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Tanker weighing.</p> <p>Exit route signs.</p> <p>Hazchem/Tremcards as necessary.</p> <p>Who checks the vehicle for integrity and cleanliness before despatch?</p> | <p>Check provision of fire alarms, extinguishers, emergency cut-offs.</p> <p>Provision of adsorbents.</p> <p>Water supplies.</p> <p>Emergency supplies.</p> <p>Emergency showers. Eyewash provisions. First aid.</p> <p>Communications.</p> <p>Liaison with emergency services.</p> <p>Procedures for dealing with the media.</p> |
| <p><b>Emergencies</b></p> <p>Check fire-fighting capability and access for fire appliances.</p> <p>Foam make-up provisions.</p>                                      |                                                                                                                                                                                                                                                                                                                                   |

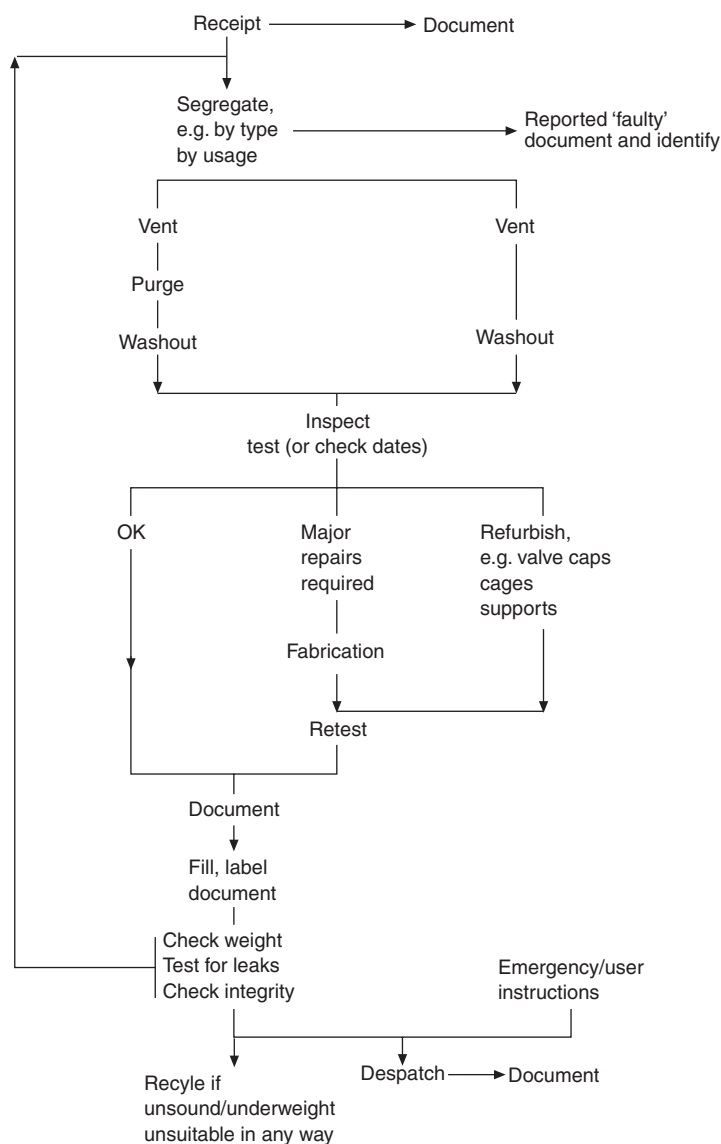


Figure 15.4 Procedure for refilling returnable chemical containers

## Container filling/discharging

Considerations for the safe filling/discharging of containers will normally include:

- A segregated area adequately spaced from ignition sources, etc. with provision for spillage control and with appropriate protection from vehicle impact.

- Avoidance of overhead piping, e.g. process lines, water, steam.

- Adequate weather protection, both for operators and to avoid ingress of rainwater or other contaminants.

- Provision of information and instruction to personnel as to the hazards with the specific chemical, including possible reactions.

- Thorough inspection of containers for integrity, correct labelling, sound valves or closures.

Figure 15.4 shows a procedure for the refilling of returnable containers with a chemical of assured quality. (This will require some combination of documentation, sampling and analysis to ensure that the chemical is of the correct type, and in the intended condition.) This is applicable to drums and plastic containers, and bottles, but some modifications are necessary for pressure systems, i.e. gas cylinders, covered by the Pressure Systems Safety Regulations 2000 including:

- A check from marks on the cylinder indicating that it has undergone proper examination at appropriate intervals by a competent person.

- All appropriate safety checks including the provision of a correct valve, plug and protection cap, if appropriate.

- A check that it is not overfilled and is within its safe operating limits.

# Chemicals and the environment: sources and impact

Protection of the environment from pollution caused by 'wastes' is a matter of increasing concern. It can be a technically-complex exercise because the variety of waste is extremely wide, the volumes may be large, and the levels 'permissible' for release may be very low.

Examples of industrial chemical waste are given in Table 16.1. Common industrial sources of pollution are given in Table 16.2. Since waste can result in pollution, the two terms are often used synonymously.

**Table 16.1 Types of waste and forms of pollutant**

| <i>Source</i>                                  | <i>Type of waste</i>                 | <i>Form of pollutant<sup>(1)</sup></i> |
|------------------------------------------------|--------------------------------------|----------------------------------------|
| <b>Agriculture, horticulture</b>               | BOD waste (high and low)             | L S A                                  |
|                                                | Disinfectant                         | A                                      |
|                                                | Pesticides, herbicides (see below)   | PA                                     |
|                                                | Fertilizers, see Inorganic chemicals | A                                      |
| <b>Cement, bricks, lime</b>                    | Chromium                             | L                                      |
|                                                | Dust                                 | S                                      |
|                                                | Fluorides                            | G                                      |
|                                                | Sulphur dioxide                      | G                                      |
| <b>Coal distillation, coal tar, coke ovens</b> | Ammonia                              | G A                                    |
|                                                | Aromatic hydrocarbons                | G L                                    |
|                                                | Combustion products                  | G                                      |
|                                                | Cyanate                              | A                                      |
|                                                | Cyanides                             | G A                                    |
|                                                | Dust                                 | S P                                    |
|                                                | Fluorides                            | G A                                    |
|                                                | Hydrocarbons (general)               | G L A                                  |
|                                                | Hydrogen sulphide                    | G                                      |
|                                                | Phenols                              | L A                                    |
|                                                | Polycyclic hydrocarbons              | G                                      |
|                                                | Sulphur dioxide                      | G                                      |
|                                                | Tar                                  | G L S                                  |
|                                                | Thiocyanates                         | A                                      |
| <b>Construction, building, demolition</b>      | Combustion products                  | G P                                    |
|                                                | Dust                                 | S P                                    |

Table 16.1 Cont'd

| Source                 | Type of waste                                          | Form of pollutant <sup>(1)</sup> |
|------------------------|--------------------------------------------------------|----------------------------------|
| Electricity generation | Metals                                                 | S                                |
|                        | Rubble                                                 | S                                |
|                        | Timber                                                 | S                                |
|                        | Clinker                                                | S                                |
|                        | Combustion products, e.g. smoke                        | G                                |
|                        | Cooling water                                          | L                                |
| Fibres, textiles       | Pulverized fuel ash                                    | S P                              |
|                        | Sulphur dioxide, nitrogen dioxide                      | G                                |
|                        | Bleaches                                               | A                                |
|                        | Cyanides                                               | A                                |
|                        | Detergents                                             | A                                |
|                        | Dyestuffs                                              | A                                |
|                        | Grease                                                 | L S                              |
|                        | Oil                                                    | L A                              |
|                        | Resins                                                 | L A                              |
|                        | Silicones                                              | A                                |
|                        | Speciality chemicals for fire-, rot- and waterproofing | L A                              |
| Food processing        | Wax                                                    | PA                               |
|                        | Animal                                                 |                                  |
|                        | Abattoir waste                                         | L S P A                          |
|                        | BOD waste (high and low)                               | A                                |
|                        | Disinfectants                                          | A                                |
|                        | Grease                                                 | S A                              |
|                        | Oil                                                    | L A                              |
|                        | Beverage                                               |                                  |
|                        | Alkali                                                 | A                                |
|                        | BOD waste (low)                                        | A                                |
|                        | Carbon dioxide                                         | G                                |
|                        | Cullet                                                 | S                                |
|                        | Detergents                                             | A                                |
|                        | Vegetable and fruit                                    |                                  |
|                        | Alkali                                                 | A                                |
|                        | Bleaches                                               | A                                |
|                        | BOD waste (high and low)                               | P A                              |
|                        | Oil                                                    | L                                |
|                        | Solvents                                               | L A                              |
|                        | Wax                                                    | S P A                            |
|                        | Inorganic chemicals                                    | Chloralkali                      |
| Brine                  |                                                        | A                                |
| Calcium chloride       |                                                        | A                                |
| Mercury                |                                                        | L                                |
| Desalination           |                                                        |                                  |
| Brines                 |                                                        | A                                |
| Fertilizer             |                                                        |                                  |
| Ammonia                |                                                        | G A                              |
| Nitrates               |                                                        | S                                |
| Oxides of nitrogen     |                                                        | A                                |
| Phosphates             |                                                        | S                                |
| Glass and ceramic      |                                                        |                                  |
| Arsenic                |                                                        | A                                |
| Barium                 |                                                        | S                                |
| Manganese              |                                                        | S                                |
| Selenium               |                                                        | S                                |
| Hydrofluoric acid      |                                                        |                                  |
| Calcium sulphate       |                                                        | P A                              |
| Nitric acid            |                                                        |                                  |
| Ammonia                |                                                        | G A                              |
| Oxides of nitrogen     |                                                        | A                                |
| Phosphoric acid        |                                                        |                                  |
| Calcium sulphate       | P A                                                    |                                  |
| Hydrofluoric acid      | A                                                      |                                  |



Table 16.1 Cont'd

| <i>Source</i>                | <i>Type of waste</i>         | <i>Form of pollutant<sup>(1)</sup></i> |
|------------------------------|------------------------------|----------------------------------------|
| Pigments                     | Arsenic                      | S P                                    |
|                              | Barium                       | S P                                    |
|                              | Cadmium                      | S P                                    |
|                              | Cobalt                       | S P                                    |
|                              | Iron                         | S P A                                  |
|                              | Lead                         | S P                                    |
|                              | Manganese                    | S P                                    |
|                              | Selenium                     | S P                                    |
|                              | Titanium                     | S P                                    |
|                              | Zinc                         | S P                                    |
| Sulphuric acid               | Sulphur dioxide              | G P                                    |
| Drycleaning                  | Chlorinated hydrocarbons     | G L                                    |
|                              | Hydrocarbon solvents         | G L                                    |
| General                      | Bleaches, e.g. hypochlorites | A                                      |
|                              | Detergents                   | A                                      |
|                              | Phosphates                   | A                                      |
|                              | Sulphates                    | A                                      |
| <b>Metals</b>                |                              |                                        |
| Extraction and refining      | Acid mine waters             | A                                      |
|                              | Combustion products          | G P                                    |
|                              | Carbon monoxide              | G                                      |
|                              | Chlorides                    | G S P                                  |
|                              | Drosses                      | S                                      |
|                              | Dust                         | S                                      |
|                              | Fluorides                    | G S P                                  |
|                              | Glass                        | S                                      |
|                              | Spoil                        | S                                      |
|                              | Sulphides                    | S P A                                  |
|                              | Sulphur dioxide              | G                                      |
| Finishing/surface treatments |                              |                                        |
| Anodizing                    | Chromium                     | A                                      |
| Degreasing                   | Chlorinated hydrocarbons     | G L                                    |
|                              | Detergents                   | A                                      |
|                              | Grease; mineral-oil based    | L S                                    |
|                              | Solvents                     | G L                                    |
| Electroplating               | Alkali                       | A                                      |
|                              | Boron                        | A                                      |
|                              | Cadmium                      | A                                      |
|                              | Chromium                     | P A                                    |
|                              | Copper                       | A                                      |
|                              | Cyanides                     | A                                      |
|                              | Detergents                   | A                                      |
|                              | Fluorides                    | A                                      |
|                              | Iron                         | A                                      |
|                              | Nickel                       | A P                                    |
|                              | Organic complexing agents    | A                                      |
|                              | Phosphates                   | A                                      |
|                              | Precious metals              | A                                      |
|                              | Silver                       | A                                      |
|                              | Sulphates                    | A                                      |
|                              | Tin                          | A                                      |
|                              | Zinc                         | A                                      |
| Foundries                    | Dust                         | S P                                    |
|                              | Sands, some resin-bonded     | S                                      |
| Machine shops                | Oils                         | L A                                    |
|                              | Oil absorbents               | S                                      |
|                              | Semi-synthetic coolants      |                                        |

Table 16.1 Cont'd

| <i>Source</i>                                               | <i>Type of waste</i>  | <i>Form of pollutant<sup>(1)</sup></i> |
|-------------------------------------------------------------|-----------------------|----------------------------------------|
| Pickling                                                    | Solvents              | L G                                    |
|                                                             | Swarf, various metals | S                                      |
|                                                             | Synthetic coolants    | L S A                                  |
|                                                             | Acids                 | A                                      |
|                                                             | Ferrous chloride      | A                                      |
|                                                             | Ferrous sulphate      | A                                      |
|                                                             | Hydrochloric acid     | A                                      |
|                                                             | Hydrofluoric acid     | A                                      |
|                                                             | Nitric acid           | A                                      |
|                                                             | Phosphoric acid       | A                                      |
| Pigments, see Inorganic chemicals<br>Processing/engineering | Sulphuric acid        | A                                      |
|                                                             | Ammonia               | G A                                    |
|                                                             | Arsenic               | G S A                                  |
|                                                             | Cyanides              | S A                                    |
|                                                             | Emulsions             | A                                      |
|                                                             | Lubricating oils      | L                                      |
|                                                             | Phenols               | L S A                                  |
|                                                             | Soluble oils          | A                                      |
|                                                             | Thiocyanates          | A                                      |
| Products<br>Batteries                                       | Cadmium               | S P                                    |
|                                                             | Lead                  | S P                                    |
|                                                             | Manganese             | S                                      |
|                                                             | Mercury               | S                                      |
|                                                             | Nickel                | S                                      |
|                                                             | Zinc                  | S                                      |
| Catalysts                                                   | Cobalt                | S                                      |
|                                                             | Iron                  | S                                      |
|                                                             | Manganese             | S                                      |
|                                                             | Mercury               | S                                      |
|                                                             | Nickel                | S                                      |
|                                                             | Organometallics       | L S                                    |
|                                                             | Platinum              | S                                      |
|                                                             | Silver                | S                                      |
|                                                             | Vanadium              | S                                      |
| Mining (excluding metals)                                   | Spoil                 | S                                      |
|                                                             | Dust                  | S P                                    |
| Paint                                                       | Barium                | S                                      |
|                                                             | Cadmium               | S                                      |
|                                                             | Chromium              | S                                      |
|                                                             | Copper                | S                                      |
|                                                             | Lead                  | S                                      |
|                                                             | Manganese             | S                                      |
|                                                             | Mercury               | L S                                    |
|                                                             | Selenium              | S                                      |
|                                                             | Solvents              | G L                                    |
|                                                             | Titanium              | S                                      |
| Paper, pulp                                                 | Bleaches              | A                                      |
|                                                             | Chlorine              | G A                                    |
|                                                             | Copper                | A                                      |
|                                                             | Fibres                | S P A                                  |
|                                                             | Lignin                | A                                      |

Table 16.1 Cont'd

| <i>Source</i>                                        | <i>Type of waste</i>            | <i>Form of pollutant<sup>(1)</sup></i> |
|------------------------------------------------------|---------------------------------|----------------------------------------|
|                                                      | Mercury                         | A                                      |
|                                                      | Methanol                        | A                                      |
|                                                      | Sulphides                       | A                                      |
|                                                      | Sulphite liquor                 | A                                      |
|                                                      | Titanium                        | S P A                                  |
|                                                      | Wax                             | S P A                                  |
|                                                      | Zinc                            | P A                                    |
| <b>Pesticides, herbicides</b>                        |                                 |                                        |
|                                                      | Arsenic                         | S P A                                  |
|                                                      | Carbamates                      | S P A                                  |
|                                                      | Chlorinated hydrocarbons        | L S P A                                |
|                                                      | Copper                          | A                                      |
|                                                      | Fluoride                        | G S A                                  |
|                                                      | Lead                            | A                                      |
|                                                      | Mercury                         | L A                                    |
|                                                      | Organophosphorus compounds      | P A                                    |
|                                                      | Phenol                          | S A                                    |
|                                                      | Polychlorinated biphenyls (PCB) | A                                      |
|                                                      | Selenium                        | S                                      |
| <b>Petrochemicals</b>                                |                                 |                                        |
| Detergents                                           | Boric acid                      | S A                                    |
|                                                      | Phosphates                      | S A                                    |
|                                                      | Sulphates                       | S A                                    |
| Dyestuffs                                            | Aniline                         | L A                                    |
|                                                      | Chromium                        | L S P A                                |
|                                                      | Phenol                          | A                                      |
|                                                      | Selenium                        | L S P A                                |
| General                                              | Benzene, toluene, xylene        | L                                      |
|                                                      | Boric acid                      | A                                      |
|                                                      | Chlorocarbons                   | G L A                                  |
|                                                      | Fluorine                        | A                                      |
|                                                      | Fluorocarbons                   | G L A                                  |
|                                                      | Hydrocarbons                    | G L S P A                              |
|                                                      | Hydrochloric acid               | A                                      |
|                                                      | Hydrofluoric acid               | A                                      |
|                                                      | Phenols                         | L A                                    |
|                                                      | Solvents                        | L                                      |
|                                                      | Sulphuric acid                  | A                                      |
| Miscellaneous                                        | Polychlorinated biphenyls (PCB) | L                                      |
|                                                      | Tetraethyl lead                 | G L P                                  |
| <b>Polymers, plastics, resins, rubber and fibres</b> |                                 |                                        |
|                                                      | Acids                           | A                                      |
|                                                      | Alkali                          | A                                      |
|                                                      | Cadmium                         | L S P A                                |
|                                                      | Cuprammonium compounds          | A                                      |
|                                                      | Detergents                      | A                                      |
|                                                      | Dyestuffs                       | A                                      |
|                                                      | Fibres                          | S P                                    |
|                                                      | Formaldehyde                    | A                                      |
|                                                      | Hydrocarbons                    | G L A                                  |
|                                                      | Methanol                        | L A                                    |
|                                                      | Phenols                         | L S A                                  |
|                                                      | Phthalates                      | L A                                    |
|                                                      | Polychlorinated biphenyls (PCB) | L A                                    |
|                                                      | Solvents                        | L A                                    |

Table 16.1 Cont'd

| <i>Source</i>                 | <i>Type of waste</i>            | <i>Form of pollutant<sup>(1)</sup></i> |
|-------------------------------|---------------------------------|----------------------------------------|
|                               | Sulphides                       | A                                      |
|                               | Urea                            | S A                                    |
|                               | Wood flour, various woods       | S P                                    |
|                               | Zinc                            | A                                      |
| <b>Pharmaceuticals</b>        | Drug intermediates and residues | L S A                                  |
|                               | Solvents                        | L A                                    |
| <b>Refineries (Petroleum)</b> | Alkali                          | A                                      |
|                               | BOD waste                       | L P A                                  |
|                               | Combustion products             | G                                      |
|                               | Emulsions                       | A                                      |
|                               | Hydrocarbons                    | L A                                    |
|                               | Mercaptans                      | G                                      |
|                               | Mineral acids                   | A                                      |
|                               | Phenols                         | L S P A                                |
|                               | Sulphides                       | G S P                                  |
|                               | Sulphur                         | S P                                    |
|                               | Tars                            | S P                                    |
| <b>Sewage treatment</b>       | Purified effluent               | L                                      |
|                               | Sewage sludge                   | S A                                    |
| <b>Tanneries</b>              | Arsenic                         | A                                      |
|                               | Chromium                        | A                                      |
|                               | Fibres                          | S P                                    |
|                               | Hair                            | S P                                    |
|                               | Lime                            | P A                                    |
| <b>Textiles, see Fibres</b>   |                                 |                                        |
| <b>Miscellaneous</b>          | Sulphides                       | A                                      |
| Electrical, electronics       | Copper                          | S                                      |
|                               | Mercury                         | L                                      |
|                               | Precious metals                 | S                                      |
|                               | Selenium                        | S                                      |
| Explosives, pyrotechnics      | Barium                          | S                                      |
|                               | Hydrocarbons                    | G L A                                  |
|                               | Lead                            | S                                      |
|                               | Manganese                       | S P                                    |
|                               | Mercury                         | L S P                                  |
|                               | Nitric acid                     | A                                      |
|                               | Nitroglycerin                   | L A                                    |
|                               | Phenol                          | S P                                    |
|                               | Phosphorus                      | S                                      |
|                               | Solvents                        | G L                                    |
|                               | Strontium                       | S                                      |
|                               | TNT                             | L A                                    |
| Motor industry                | Chromates                       | A                                      |
|                               | Grease; mineral-oil based       | L S                                    |
|                               | Oil                             | L                                      |
|                               | Paint                           | L S P                                  |
|                               | Phosphates                      | S P A                                  |
|                               | Solvents                        | L                                      |
| Nuclear fuel and power        | Radioactive substances          |                                        |
|                               | Radioisotopes                   |                                        |
| Photography                   | Alkali                          | A                                      |

Table 16.1 Cont'd

| Source          | Type of waste         | Form of pollutant <sup>(1)</sup> |
|-----------------|-----------------------|----------------------------------|
| Vehicle exhaust | Cyanide               | A                                |
|                 | Mercury               | A                                |
|                 | Phenols               | A                                |
|                 | Silver                | P A                              |
|                 | Thiosulphate          | A                                |
|                 | Aromatic hydrocarbons | G                                |
|                 | Lead                  | S P                              |
| Water treatment | Nitrogen oxides       | G                                |
|                 | Calcium salts         | A P                              |
|                 | Filtered solids       | L P A                            |

<sup>(1)</sup> G Pollutant occurs as a gas

L Pollutant occurs as a liquid

S Pollutant occurs as a solid

P Pollutant occurs in particulate form

A Pollutant occurs in aqueous solution or suspension

Table 16.2 Common sources of pollutants

| Chemical                      | Form of pollutant <sup>(1)</sup> | Examples                                           | Industrial source                                                                                         |
|-------------------------------|----------------------------------|----------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Acid Mineral                  | A                                | Hydrochloric acid<br>Nitric acid<br>Sulphuric acid | Pickling of metals<br>Chemical reagent                                                                    |
| Organic                       | A                                | Acetic acid                                        | Byproducts, petrochemicals                                                                                |
| Aldehydes                     | A                                | Acetaldehyde                                       | Petrochemicals<br>Photochemical reaction in smog, incomplete combustion                                   |
| Alkali                        | P A                              | Sodium hydroxide<br>Lime                           | Petrochemicals<br>Electroplating<br>Beverages production<br>Photography                                   |
| Ammonia                       | G A                              | –                                                  | Vegetable and fruit processing<br>Coal distillation (coke ovens)<br>Nitric acid production                |
| Aniline and related compounds | L A                              | –                                                  | Urea and ammonium nitrate works<br>Dyestuffs production                                                   |
| Aromatic hydrocarbons         | G L                              | Benzene<br>Toluene<br>Xylene                       | Coal tar distillation<br>Vehicle exhausts<br>Petrochemicals<br>Pesticides<br>Herbicides                   |
| Arsenic                       | G S P A                          | Arsine<br>Arsenous acid and salts                  | Pigment and dye<br>Pesticide and herbicide production<br>Metallurgical processing of other metals         |
| Asbestos                      | S P                              | Chrysotile<br>Amosite<br>Crocidolite               | Glass and ceramics industries<br>Tanneries<br>Obsolete building products<br>Insulation removal operations |
| Carbon dioxide                | G A                              |                                                    | Combustion<br>Fermentation                                                                                |

Table 16.2 Cont'd

| <i>Chemical</i>          | <i>Form of pollutant<sup>(1)</sup></i> | <i>Examples</i>                                                      | <i>Industrial source</i>                                                                                                |
|--------------------------|----------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| Carbon monoxide          | G                                      |                                                                      | Coke ovens<br>Incomplete combustion generally<br>Smelting<br>Vehicle exhausts<br>Metal extraction and refining          |
| Chlorinated hydrocarbons |                                        |                                                                      |                                                                                                                         |
| Chemical                 | G L                                    | Trichloroethylene;<br>1,1,1-trichloroethane<br>(obsolescent)         | Degreasing (engineering)<br>Drycleaning<br>Solvents                                                                     |
| Pesticidal               | L S                                    | DDT<br>BHC<br>Aldrin<br>Dieldrin                                     | Pesticides<br>Wood treatment                                                                                            |
| Chlorine and chlorides   | G<br>S P A                             |                                                                      | Chlorinated hydrocarbons<br>Chloralkali<br>Paper and pulp processing<br>Petrochemicals<br>Metal extraction and refining |
| Chromium and compounds   | S P A                                  | Chromic acid<br>Sodium dichromate                                    | Anodizing<br>Cement<br>Dyes<br>Electroplating<br>Paint<br>Tanneries                                                     |
| Cobalt and compounds     | S P A                                  | Cobalt oxide                                                         | Catalysts<br>Fibres<br>Paint<br>Paper and pulp processing<br>Tungsten carbide binder                                    |
| Copper and compounds     | S P A                                  | Copper sulphate<br>Copper pyrophosphate<br>Cuprammonium<br>compounds | Electroplating<br>Electrical and electronics<br>Etching<br>Pesticides                                                   |
| Cyanate                  | A                                      |                                                                      | Coal distillation<br>Oxidation of cyanide                                                                               |
| Cyanide                  | S P A                                  | Sodium cyanide<br>Copper cyanide                                     | Heat treatment of metal<br>Coal distillation<br>Electroplating<br>Photographic<br>Synthetic fibre                       |
| Disinfectants            |                                        |                                                                      | Agriculture and horticulture<br>Abattoirs<br>Food processing                                                            |
| Fluorides                | G S P A                                | Hydrogen fluoride<br>Calcium fluoride                                | Cement<br>Aluminium                                                                                                     |
| Hydrocarbons, general    |                                        |                                                                      | Coal distillation<br>Petrochemicals<br>Petroleum refineries                                                             |
| Iron and compounds       | S P A                                  | Iron oxide<br>Ferrous chloride                                       | Aluminium refining<br>Steelworks<br>Electronics<br>Electroplating<br>Pickling<br>Pigments                               |

Table 16.2 Cont'd

| <i>Chemical</i>                                                                                                                                           | <i>Form of pollutant<sup>(1)</sup></i> | <i>Examples</i>                                                                           | <i>Industrial source</i>                                                                                                                                                                                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lead and compounds                                                                                                                                        | S P A                                  | Lead oxide<br>Tetraethyl lead (TEL)                                                       | Batteries<br>Explosives and pyrotechnics<br>Paint<br>Pesticides<br>Petrochemicals<br>Printing<br>Refineries<br>Vehicle exhausts                                                                                                         |
| Manganese and compounds                                                                                                                                   |                                        |                                                                                           | Batteries<br>Catalyst<br>Glass<br>Paint<br>Pyrotechnics                                                                                                                                                                                 |
| Meat wastes                                                                                                                                               | S A                                    |                                                                                           | Meat processing and preparation<br>Abattoirs<br>Dairies<br>Tanneries                                                                                                                                                                    |
| Mercaptans                                                                                                                                                | G                                      |                                                                                           | Refineries<br>Coke ovens<br>Herbicides                                                                                                                                                                                                  |
| Mercury<br>Organic                                                                                                                                        | S A                                    | Methyl mercury                                                                            | Bacterial activity on inorganic mercury<br>Pesticides                                                                                                                                                                                   |
| Inorganic                                                                                                                                                 | L S A                                  | Mercurous chloride                                                                        | Batteries<br>Catalysts<br>Cement<br>Chloralkali process<br>Combustion of coal and oil<br>Electrical and electronic<br>Explosives<br>Paints<br>Paper and pulp<br>Pesticides<br>Pharmaceuticals<br>Photographic<br>Scientific instruments |
| Methanol                                                                                                                                                  | L A                                    |                                                                                           | Paper<br>Resins                                                                                                                                                                                                                         |
| Nitrates                                                                                                                                                  | S P                                    | Potassium nitrate                                                                         | Metals heat treatment<br>Water treatment                                                                                                                                                                                                |
| Nitrogen oxides                                                                                                                                           | G                                      | Nitrogen dioxide                                                                          | Combustion processes and explosives<br>Electricity generation<br>Forge tower silos<br>Nitric acid                                                                                                                                       |
| Oil and soluble oil                                                                                                                                       | L                                      |                                                                                           | Engineering<br>Petrochemicals<br>Refineries                                                                                                                                                                                             |
| Paraquat<br>Pesticides (includes<br>acaricides, avicides,<br>bactericides, insect-<br>icides, molluskicides,<br>nematocides, piscicides,<br>rodenticides) | L S                                    | Chlorinated hydrocarbons (q.v.)<br>Carbamates (q.v.)<br>Organophosphorus compounds (q.v.) | Herbicide                                                                                                                                                                                                                               |
| Pharmaceuticals                                                                                                                                           | L S P A                                | Aspirin<br>Penicillin                                                                     | Pharmaceutical industry                                                                                                                                                                                                                 |

Table 16.2 Cont'd

| <i>Chemical</i>                 | <i>Form of pollutant<sup>(1)</sup></i> | <i>Examples</i>                     | <i>Industrial source</i>                                                                                                            |
|---------------------------------|----------------------------------------|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Phenol and related compounds    | S P A                                  | Phenol<br>Cresol                    | Coal distillation<br>Dyestuffs<br>Explosives<br>Pesticides<br>Petrochemicals<br>Photographic<br>Plastics manufacture<br>Refineries  |
| Phosphorus and compounds        | S P A                                  | Phosphoric acid                     | Boiler blowdown<br>Corrosion protection<br>Detergents<br>Fertilizers<br>Matches<br>Metal finishing                                  |
| Phthalates                      | L S P A                                | Dibutyl phthalate                   | Adhesives                                                                                                                           |
| Platinum and compounds          | S P                                    |                                     | Catalysts                                                                                                                           |
| Polychlorinated biphenyls (PCB) | L S A                                  |                                     | Lubricants and hydraulic fluids<br>Pesticides<br>Plasticizer in paint and polymers<br>Plasticizer (polymers)<br>Transformer oils    |
| Silicates                       | P                                      |                                     | Cement<br>Metal extraction and refining                                                                                             |
| Sulphur oxides                  | G                                      | Sulphur dioxide<br>Sulphur trioxide | Coal distillation<br>Combustion of coal and heavy fuel oil<br>Detergents (sulphonation of alkyl benzenes)<br>Electricity generation |
| Tar                             | L                                      |                                     | Refineries<br>Coal distillation                                                                                                     |
| Thiocyanate                     | A                                      |                                     | Coal distillation                                                                                                                   |
| Tin and compounds               | G S P A                                |                                     | Tinplating                                                                                                                          |
| Titanium and compounds          | S P A                                  | Titanium dioxide                    | Astronautics<br>Paint<br>Paper                                                                                                      |
| Vanadium and compounds          | S P                                    | Catalysts                           | Animal feed                                                                                                                         |
| Vegetable waste                 | L S P A                                |                                     | Breweries<br>Natural rubber<br>Starch<br>Sugar refineries<br>Vegetable and fruit processing and preparation                         |
| Wax                             | S                                      |                                     | Fruit preserving<br>Paper<br>Refineries                                                                                             |
| Zinc and compounds              | G S P A                                |                                     | Textiles<br>Electroplating<br>Galvanizing<br>Paper and pulp<br>Synthetic fibres                                                     |

<sup>(1)</sup> G Pollutant occurs as a gas  
 L Pollutant occurs as a liquid  
 S Pollutant occurs as a solid  
 P Pollutant occurs in particulate form  
 A Pollutant occurs in aqueous solution or suspension



Conventionally, wastes are considered as being predominantly either solid, liquid or gaseous but as illustrated in Table 16.3, they may be multi-phase. Solid waste comprises liquid slurries, sludges, thixotropic solids and solids of varying particle sizes; it may be heterogeneous. Typical examples are given in Table 16.4.

**Table 16.3 Some physical forms of waste**

| <i>Phase</i>     | <i>Examples</i>   |                                                                        |
|------------------|-------------------|------------------------------------------------------------------------|
| <b>Gas</b>       |                   |                                                                        |
| Gas–vapour       | –                 | SO <sub>2</sub> ; NO <sub>x</sub> ; HCl; CO; hydrocarbons              |
| Gas–liquid       | Mist              | Acid mist carryover; chromic acid; oil mists; tar fog                  |
| Gas–solid        | Fume              | Metal oxides, cement dust                                              |
| Gas–liquid–solid | –                 | Paint spray                                                            |
| <b>Liquid</b>    |                   |                                                                        |
| Liquid           | Solution          | Metal plating effluent; ‘spent’ acids; wash-waters                     |
| Liquid–gas       | Foam              | Detergent foam                                                         |
| Liquid–liquid    | Emulsions         | Oil-in-water (e.g. suds); water-in-oil                                 |
| Liquid–solid     | Slurry            | Aqueous effluent from fume scrubbing                                   |
|                  | Suspension        |                                                                        |
| <b>Solid</b>     |                   |                                                                        |
| Solid            | –                 | Asbestos insulation; heat treatment salts, pulverized fuel ash; refuse |
| Solid–liquid     | Sludge, wet solid | Filter cake<br>Sewage sludge                                           |

Waste treatment prior to disposal may introduce phase changes which result in quite different pollution control considerations. For example, the gases generated by incineration of a solid waste can be scrubbed with liquid in order to meet an acceptable discharge criterion; hence, in addition to ash for disposal, a liquid effluent stream is produced and requires treatment. Other waste treatment processes may result in the liberation of flammable or toxic gaseous emissions as exemplified in Table 16.5.

Pollutants may enter the environment via air, water or land and prove:

Damaging to the environment or public health and well-being.

Damaging to buildings and materials of construction (Table 16.6).

Wasteful of valuable resources.

Illegal.

Technically difficult and expensive to deal with (e.g. to clean up spillages and rectify damage).

Harmful to company reputation.

The range of measures applicable to control are summarized in Chapter 17. Recycling and recovery are potentially attractive measures; hence solvents, mineral oils, metals, e.g. lead, copper, nickel, mercury, and glass are commonly recycled. However, recycling options generally depend upon favourable economics, particularly low collection costs.

The two different, but related, considerations in waste disposal are hazard control and loss prevention in the treatment and disposal operations, and the control of environmental hazards. With gas and liquid streams the control of on-site hazards arising from the chemical properties and processing operations generally follows the principles summarized in earlier chapters. The measures necessary with ‘solid’ wastes may, however, differ, particularly if they are heterogeneous in nature and disposed of on land.

**Table 16.4 Major solid wastes: origin, quantities and destination**

| <i>Type</i>                                                | <i>Origin</i>                                                 | <i>Method of disposal</i>                                                                             | <i>Present uses</i>                                                                                                       |
|------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Colliery spoil                                             | Mining                                                        | Mainly tipping on land,<br>some in sea<br>Some used                                                   | As fill and in manufacture<br>of bricks, cement and<br>lightweight aggregate                                              |
| China clay waste,<br>overburden sand,<br>micaceous residue | Quarrying                                                     | Mainly tipping and in<br>lagoons<br>Some used                                                         | As fine aggregate in<br>concrete, in<br>manufacture of bricks<br>and blocks and as fill                                   |
| Household refuse                                           | Household                                                     | Mainly landfill<br>Some incineration                                                                  | Some resource and energy<br>recovery                                                                                      |
| Pulverized fuel ash and<br>furnace bottom ash              | Waste from power stations<br>burning pulverized coal          | Some used<br>Remainder in old workings<br>or artificial lagoons                                       | As fill and in manufacture<br>of cement, concrete<br>blocks, light-weight<br>aggregate, bricks etc.                       |
| Blastfurnace slag                                          | Iron smelting                                                 | Nearly all used                                                                                       | As roadstone, railway<br>ballast, filter medium,<br>aggregate for concrete,<br>fertilizer and in<br>manufacture of cement |
| Trade waste                                                | Industry                                                      | Mainly landfill<br>Some incineration                                                                  | Unknown                                                                                                                   |
| Steel-making slag                                          | Steel making                                                  | Some returned to blast-<br>furnaces, remainder<br>dumped or used as fill<br>near steel works, or sold | As roadstone                                                                                                              |
| Furnace clinker                                            | Waste from chain grate<br>power stations                      | All used                                                                                              | Concrete block making                                                                                                     |
| Incinerator ash                                            | Residue from direct<br>incineration                           | Most dumped<br>Minor usage                                                                            | As fill and for covering<br>refuse tips                                                                                   |
| Byproduct calcium<br>sulphate                              | Manufacture of<br>phosphoric acid and of<br>hydrofluoric acid | Mainly in sea. Some<br>dumped on land<br>Some used                                                    | In manufacture of floor<br>screeds                                                                                        |
| Waste glass                                                | Waste glass within<br>household refuse                        | No utilization in<br>household refuse                                                                 | If segregated, recycled                                                                                                   |
| Slate waste                                                | Mining and quarrying slate                                    | Mainly tipping, some<br>backfilling of old<br>workings<br>Minor usage                                 | Inert filler, granules,<br>expanded slate<br>aggregate and filter<br>medium, road building                                |
| Tin mine tailings                                          | Tin mining                                                    | Minor utilization. Tailing<br>lagoons and discharge<br>into sea                                       | Aggregate for concrete                                                                                                    |
| Fluorspar mine tailings                                    | Fluorspar mining                                              | Minor utilization<br>Tailing lagoons                                                                  | Aggregate for roadmaking<br>and concrete                                                                                  |
| Red mud                                                    | Production of alumina                                         | Minor utilization, rest in<br>lagoons                                                                 | Pigment in paints and<br>plastics                                                                                         |
| Copper slag                                                | Smelting                                                      | Complete utilization                                                                                  | Grit blasting                                                                                                             |
| Tin slag                                                   | Smelting                                                      | Major utilization<br>Some in tips                                                                     | Grit blasting and road<br>building                                                                                        |
| Zinc-lead slags                                            | Smelting of zinc and lead                                     | Stockpiled and used<br>locally                                                                        | Bulk fill and some in<br>pavement asphalt                                                                                 |
| Quarry wastes                                              | Quarrying                                                     | Some utilization<br>Remainder tipped                                                                  | Roadmaking, brickmaking                                                                                                   |

**Table 16.5 Examples of hazardous gases generation from waste pretreatment processes**

| <i>Process</i>                                                                                                      | <i>Associated problems</i>                                                        | <i>Hazardous airborne contaminants liberated (in addition to the principal reagents)</i> |
|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Neutralization of strong mineral acids from metal finishing trades (sulphide and hypochlorite contamination common) | Fierce reaction<br>Possibility of mixing with water or organic materials          | Chlorine<br>Nitrogen dioxide<br>Sulphur dioxide<br>Hydrogen sulphide                     |
| Chlorination/oxidation of cyanide wastes from heat treatment plant                                                  | Mixing cyanide with acids liberates hydrogen cyanide                              | Hydrogen cyanide                                                                         |
| Separation of oil and water mixtures from engineering and heat raising plant                                        | Emulsion splitting may involve generation of heat, hydrogen and hydrogen sulphide | Hydrogen<br>Hydrogen sulphide<br>Phosphine                                               |
| Detoxification of chromic acid and chromium salts from the plating industry                                         | Use of sulphite                                                                   | Sulphur dioxide                                                                          |
| Detoxification of by-products from smelting                                                                         | Water and weak acids liberate attack gas                                          | Arsine<br>Phosphine                                                                      |
| Treatment of ammonia-bearing waste from chemical industry                                                           | Liberation of gaseous ammonia                                                     | Ammonium chloride<br>Nitric acid                                                         |
| Removal of sulphides from leather industry waste                                                                    | Generation of sulphide gas                                                        | Hydrogen sulphide                                                                        |

The common practice in waste management is either to recycle waste or to treat and dispose of it at the end of a process. However, many 'end-of-pipe' treatment processes simply transfer a waste, albeit sometimes in a different chemical form, from one environmental medium (i.e. air, land or water) to another often at high dilution.

It would obviously be desirable to eliminate the generation of waste. Practical alternatives are to minimize it by reduction at source or to recycle it. Table 16.7 illustrates the hierarchy of waste minimization practices. Source reduction includes increased process efficiency; economies in the use of energy are also relevant, e.g. it may result in a decrease in the consumption of fossil fuels:

so reducing the air pollutants generated; or  
reducing boiler operation, with a consequent decrease in the discharge of cooling water and boiler-blowdown discharges.

'Accidental' pollution incidents arise from spillages, gas emissions, and liquid discharges sometimes in transportation. The main considerations are prevention, containment, and effective mitigatory and emergency action according to the principles outlined in earlier chapters. Effective clean-up and decontamination are then needed.

The more common requirement to control routine disposal and dispersion of solid, liquid or gaseous pollutants is based upon different criteria, e.g. their persistence in the environment (as with the effects attributed to ozone-depleting gases, or the problem of heavy metal contamination

**Table 16.6 Effects of major pollutants on materials**

| <i>Pollutant</i>                       | <i>Primary materials attacked</i>                                                                                                                               | <i>Typical effect</i>                                                                                                                                                                                            |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Carbon dioxide                         | Building stone e.g. limestone                                                                                                                                   | Deterioration                                                                                                                                                                                                    |
| Sulphur oxides                         | Metals<br>Ferrous metals<br>Copper<br>Aluminium<br>Building materials<br>(limestone, marble, slate, mortar)<br>Leather<br>Paper<br>Textiles (natural/synthetic) | Corrosion<br>Corrosion to copper sulphate (green)<br>Corrosion to aluminium sulphate (white)<br>Leaching, weakening<br>Embrittlement, disintegration<br>Embrittlement<br>Reduced tensile strength, deterioration |
| Hydrogen sulphide                      | Metals<br>Silver<br>Copper<br>Paint                                                                                                                             | Tarnish<br>Tarnish<br>Leaded paint blackened by formation of lead sulphide                                                                                                                                       |
| Ozone                                  | Rubber and elastomers<br>Plastics<br>Textiles (natural/synthetic)<br>Dyes                                                                                       | Cracking, weakening<br>Degradation, weakening<br>Weakening<br>Fading                                                                                                                                             |
| Nitrogen oxides                        | Dyes                                                                                                                                                            | Fading                                                                                                                                                                                                           |
| Hydrogen fluoride                      | Glass                                                                                                                                                           | Etching, becoming opaque                                                                                                                                                                                         |
| Solid particulates<br>(soot, tars)     | Building materials<br>Painted surfaces<br>Textiles                                                                                                              | Soiling<br>Soiling<br>Soiling                                                                                                                                                                                    |
| Acid water (pH <6.5)                   | Cement and concrete                                                                                                                                             | Slow disintegration                                                                                                                                                                                              |
| Ammonium salts                         |                                                                                                                                                                 | Slow to rapid disintegration<br>If cement is porous, corrosion of steel reinforcement may occur<br>May cause slow disintegration                                                                                 |
| Fats, animal or vegetable oils         |                                                                                                                                                                 |                                                                                                                                                                                                                  |
| Calcium chloride                       |                                                                                                                                                                 | May cause steel corrosion if concrete is porous/cracked                                                                                                                                                          |
| Calcium sulphate (and other sulphates) |                                                                                                                                                                 | Disintegrates concrete of inadequate sulphate resistance                                                                                                                                                         |
| Solvents                               | Plastics, rubber                                                                                                                                                | May cause changes due to penetration                                                                                                                                                                             |
| Oxalic acid                            |                                                                                                                                                                 | Beneficial: reduces effects of CO <sub>2</sub> , salt water, dilute acetic acid                                                                                                                                  |
| Paraffin                               |                                                                                                                                                                 | Slow penetration, not harmful                                                                                                                                                                                    |
| Phenol (5% solution)                   |                                                                                                                                                                 | Slow disintegration                                                                                                                                                                                              |
| Caustic alkali                         |                                                                                                                                                                 | Not harmful <10–15% concentration                                                                                                                                                                                |

of land), synergistic effects (as with the enhanced toxicological effects of smoke in the presence of sulphur dioxide) or long-term cumulative effects. Thus the different considerations relating to occupational compared with environmental exposures to air pollutants are exemplified in Table 16.8.

## Atmospheric emissions

### Sources

Important atmospheric pollutants comprise smoke, dust, grit, fumes and gases. Types of emission are shown in Table 16.9.

**Table 16.7 Waste minimization in the hierarchy of waste management practices**

|                         |                                                                                                                                                                                                                                    |                      |                             |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-----------------------------|
| <b>Elimination</b>      | Complete elimination of waste                                                                                                                                                                                                      | Higher priority<br>↑ | Waste minimization          |
| <b>Source reduction</b> | Avoidance, reduction or elimination of waste, generally within the confines of the production unit, through changes in industrial processes or procedures                                                                          |                      |                             |
| <b>Recycling</b>        | Use, reuse and recycling of wastes for the original or some other purpose, e.g. input material, materials recovery or energy production                                                                                            |                      |                             |
| <b>Treatment</b>        | Destruction, detoxification, neutralization, etc. of wastes into less harmful substances                                                                                                                                           | Lower priority<br>↓  | Treatment and safe disposal |
| <b>Disposal</b>         | Discharge of wastes to air, water or land in properly controlled, or safe, ways such that compliance is achieved. Secure land disposal may involve volume reduction, encapsulation, leachate containment and monitoring techniques |                      |                             |

**Table 16.8 Factors in exposure and effects of air pollutants**

| <i>Exposure</i>               | <i>Occupational</i>                                                                                                                                                                              | <i>Environmental</i>                                                                                                                                                                                                 |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Population                    | Adults (16–65)                                                                                                                                                                                   | All population including infants, aged, infirm hypersensitive subjects                                                                                                                                               |
| Period                        | Fit for work; possibly monitored<br>Basic working week, e.g. <40 hr/wk, 48 wk/yr plus overtime; therefore intermittent elimination and recovery times. Holidays excepted                         | Continual unless area vacated; therefore elimination and recovery depend on irregular periods of low/zero concentrations                                                                                             |
| Levels                        | Possibly measurable fractions of OESs (mg/m <sup>3</sup> )                                                                                                                                       | Normally very low: at limits of analytical/instrumental sensitivity (g/m <sup>3</sup> )                                                                                                                              |
| Dust, fume, gas, vapour, mist | Generally single pollutants<br>Known origin<br>Hazards probably known<br>Recognized problem<br>Personal protection and possibly health surveillance provided<br>Probably freshly formed/released | Mixture of primary pollutants, from different sources and secondary pollutants. Possible additive or synergistic effects<br>Origins may be difficult to prove<br>Hazards not quantified<br>Exposure largely unheeded |
| Concern                       | Probably freshly formed/released<br>Specific effects, therefore increased costs, accident rate; reduced productivity                                                                             | Decreased well-being<br>Non-specific respiratory troubles<br>Irritation of eyes, nose and throat<br>Damage to property and vegetation<br>Injury to animals<br>Decrease in 'amenity'<br>Long-term ecological effects  |

Combustion processes are the most important source of air pollutants. Normal products of complete combustion of fossil fuel, e.g. coal, oil or natural gas, are carbon dioxide, water vapour and nitrogen. However, traces of sulphur and incomplete combustion result in emissions of carbon monoxide, sulphur oxides, oxides of nitrogen, unburned hydrocarbons and particulates. These are 'primary pollutants'. Some may take part in reactions in the atmosphere producing 'secondary pollutants', e.g. photochemical smogs and acid mists. Escaping gas, or vapour, may

**Table 16.9 Continuous/intermittent emissions to atmosphere**

|                   |                                                    |                                                                           |
|-------------------|----------------------------------------------------|---------------------------------------------------------------------------|
| <b>High level</b> |                                                    |                                                                           |
| Routine           | Vents                                              | General ventilation (factory atmosphere)                                  |
|                   | Flare stacks                                       | Local extraction (dust, fumes, odour)                                     |
|                   | Chimney                                            | Normal flaring                                                            |
| Irregular         | Plant maloperation                                 | Process plant                                                             |
|                   |                                                    | Dust and fume extraction plant                                            |
|                   | Flare stack                                        | Emergency/occasional flaring                                              |
|                   | Plant failure                                      | Process plant – emergency venting                                         |
|                   |                                                    | Extraction/collection plant (cyclones, precipitators, filters, scrubbers) |
| <b>Low level</b>  |                                                    |                                                                           |
| Routine           | Process equipment cleaning                         |                                                                           |
|                   | Materials handling (discharge, conveying, bagging) |                                                                           |
|                   | Waste handling/deposition                          |                                                                           |
| Irregular         | Plant maloperation (e.g. unauthorized ‘venting’)   |                                                                           |
|                   | Plant failure – spillages, pipe joint failures     |                                                                           |
|                   | Start-up/shutdown                                  |                                                                           |
|                   | Dismantling/demolition                             |                                                                           |
|                   | Unauthorized waste incineration (rubbish burning)  |                                                                           |
|                   | Fires                                              |                                                                           |

also be associated with the storage or processing of volatile materials or ‘accidents’ which occur in handling and transportation.

Dust can be emitted wherever solids are mined (e.g. in quarries), processed (e.g. flour mills, woodworking factories, metal smelting and foundries), or handled/transported in particulate form. Construction and demolition operations also generate dust.

In Table 16.9 emissions are classified as ‘persistent’ or ‘irregular’, and as to the level (i.e. the height above ground) at which they are likely to be generated.

## ***Effects***

The effects of atmospheric pollution are chemical, and concentration, specific. However, additive, and sometimes synergistic, effects arising from mixtures are important. A summary of the potential effects of common air pollutants is given in Table 16.10.

As noted above (Table 16.8), in considering a limit on concentration at ground level to ensure that there is no significant risk to health of local residents it is essential to recognize the important difference from occupational exposure. Thus the Occupational Exposure Limits quoted in Chapter 5 cannot readily be extrapolated to assess or control non-occupational exposure. Damage to animals, vegetation and growing crops (which can occur at extremely low levels with some pollutants) and to buildings, etc. must also be considered.

## **Liquid effluents**

### ***Sources***

The manner by which aqueous-based waste streams may arise in a factory from process uses of

**Table 16.10 Major atmospheric pollutants and their effects**

| <i>Contaminant</i>    | <i>Manmade source</i>                                                                                                                 | <i>Effects</i>                                                                                          |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Sulphur dioxide       | Combustion of coal, oil and other sulphur-containing fuels<br>Petroleum refining, metal smelting, paper-making                        | Vegetation damage<br>Sensory and respiratory irritation<br>Corrosion<br>Discoloration of buildings      |
| Hydrogen sulphide     | Various chemical processes<br>Oil wells, refineries<br>Sewage treatment                                                               | Odours, toxic<br>Crop damage/reduced yields                                                             |
| Carbon monoxide       | Vehicle exhaust and other combustion processes                                                                                        | Adverse health effects                                                                                  |
| Carbon dioxide        | Combustion processes                                                                                                                  | 'Greenhouse' effects                                                                                    |
| Nitrogen oxides       | High-temperature reaction between atmospheric nitrogen and oxygen, e.g. during combustion<br>Byproduct from manufacture of fertilizer | Adverse health effects<br>Sensory irritants<br>Reduced visibility<br>Crop damage                        |
| Ammonia               | Waste treatment                                                                                                                       | Odour<br>Irritant                                                                                       |
| Fluorides             | Aluminium smelting<br>Manufacture of ceramics, fertilizer                                                                             | Crop damage<br>HF has adverse health effects on cattle fed on contaminated food                         |
| Lead                  | Combustion of leaded petrol<br>Solder, lead-containing paint<br>Lead smelting                                                         | Adverse health effects                                                                                  |
| Mercury               | Manufacture of certain chemicals, paper, paint<br>Pesticides<br>Fungicides                                                            | Adverse health effects                                                                                  |
| Volatile hydrocarbons | Motor vehicles<br>Solvent processes<br>Chemical industry                                                                              | Vegetation damage (especially unsaturated hydrocarbons)<br>Some are irritants<br>Adverse health effects |
| Particulates          | Chemical processes<br>Fuel combustion<br>Construction<br>Incineration processes<br>Motor vehicles                                     | Nuisance<br>Adverse health effects<br>Reduced visibility<br>Deposition on buildings                     |

water, cooling water, wash-rooms and canteens, and steam-raising is exemplified in Figure 16.1. Within the UK the majority are treated prior to discharge to sewers operated by a sewage undertaker. Following further treatment they are then discharged to natural waters or the open sea. Some effluents are subjected to treatment by the producer before similar final discharge.

Strict control is necessary over pollutant levels, acidity, temperature, turbidity, etc. because of their impact upon aquatic environments. Common pollutants in aqueous effluents are identified in Table 16.11.

### ***Effects***

The pH of rainwater is normally about 6 but can be reduced significantly by absorption of acidic exhaust gases from power stations, industrial combustion or other processes, and vehicles. Acids may also enter the waterways as a component of industrial effluent. In addition to the direct adverse effects on aquatic systems (Table 16.12) low pH can result in the leaching of toxic metals from land, etc.

The salts of the heavy metals beryllium, cadmium, chromium, copper, lead, mercury, nickel and zinc are all of high eco-toxicity. For example, the toxicity of some heavy metals to rainbow trout is demonstrated in Table 16.13; coarse fish are somewhat more resistant.

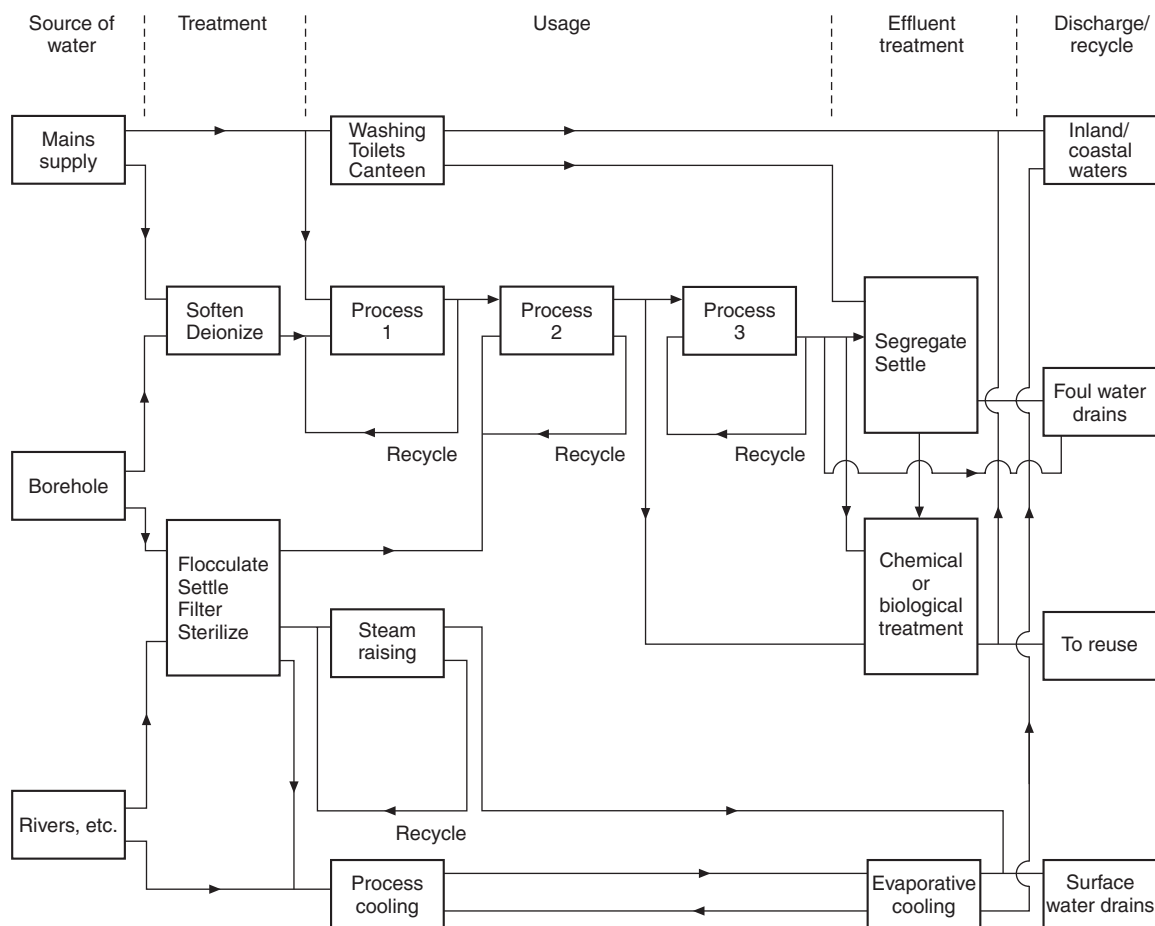


Figure 16.1 Factory water supply: usage and disposal

Fish are generally more susceptible to poisoning than microscopic plants or other animals; as such they are a good indicator species. A summary of the concentrations of selected substances at which toxic effects have been detected in bacteria, algae, crustacea and protozoa is given in Table 16.14.

Heavy metals may also be concentrated in passage up the food chain. Other pollutants, e.g. fungicides, pesticides, biocides, polychlorinated biphenyls or organic mercury compounds, are persistent and can therefore also bioaccumulate.

Cyanides can be fatal to fish at <1 ppm. Because of concern over the possible *in vivo* conversion of nitrate into carcinogenic nitrosamines, the nitrate content of drinking water must be strictly controlled. Nitrate and phosphate pollution can also cause eutrophication in still, or slow-moving, warm waters by stimulation of algae growth in the presence of strong sunshine. This chokes the water and results in depletion of light and oxygen content.

Trace contaminants such as sodium chloride, iron and phenols (especially if chlorinated) may also impart a characteristic taste if water is subsequently used for drinking purposes.

As discussed in Chapter 17, legislative controls including stringent consent conditions are applied in the UK to all discharges to specified sewers. (Discharge of effluent to surface water drains is prohibited.) Limits, or even total prohibitions, are placed upon certain chemicals to avoid



**Table 16.11 Common pollutants of aqueous effluents**

| <i>Pollutant</i>                           | <i>Example</i>                                                                                                                                                                     |
|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Alkali                                     | Sodium hydroxide (caustic soda)<br>Potassium hydroxide (caustic potash)<br>Calcium oxide (lime)<br>Calcium hydroxide<br>Sodium, potassium and calcium carbonates<br>Ammonia (q.v.) |
| Ammonia                                    |                                                                                                                                                                                    |
| Biocides                                   |                                                                                                                                                                                    |
| Biodegradable waste                        | Sewage<br>Food waste<br>Organic chemicals                                                                                                                                          |
| Boron, borates, fluoroborates              | –                                                                                                                                                                                  |
| Bromine                                    | –                                                                                                                                                                                  |
| Chloride                                   | Sodium chloride                                                                                                                                                                    |
| Chlorine                                   | Hypochlorites                                                                                                                                                                      |
| Chromic acid (hexavalent chromium)         | Potassium dichromate                                                                                                                                                               |
| Cyanide                                    | Copper cyanide<br>Nickel cyanide<br>Potassium cyanide<br>Silver cyanide<br>Sodium cyanide<br>Zinc cyanide                                                                          |
| Emulsified oil                             | Suds                                                                                                                                                                               |
| Fluoride                                   | –                                                                                                                                                                                  |
| Fluorine                                   | –                                                                                                                                                                                  |
| Metal salts in alkaline solution           | Cuprammonium complex<br>Nickel and cobalt ammonia complex<br>Cyanides (q.v.)<br>Copper pyrophosphates<br>Plumbites<br>Zincates                                                     |
| Metal salts in acid solution               | Most metals as acid salts, e.g.<br>chloride<br>nitrate<br>sulphate                                                                                                                 |
| Mineral acid                               | Hydrobromic acid<br>Hydrochloric acid<br>Hydrofluoric acid<br>Nitric acid<br>Sulphuric acid                                                                                        |
| Miscible/soluble organic materials         | Acetone<br>Alcohol<br>Acetic acid                                                                                                                                                  |
| Non-metallic inorganic dissolved compounds | Arsenic<br>Selenium                                                                                                                                                                |
| Oil, grease, wax and immiscible organics   | Lubricating oil<br>Animal fat<br>Chlorinated solvents                                                                                                                              |
| Organometallic compounds                   | –                                                                                                                                                                                  |
| pH                                         | Acids<br>Alkalis                                                                                                                                                                   |
| Pharmaceuticals                            | –                                                                                                                                                                                  |
| Phenols and related compounds              | Phenol<br>Cresol<br>Detergents                                                                                                                                                     |
| Phosphate                                  | –                                                                                                                                                                                  |
| Sewage                                     |                                                                                                                                                                                    |
| Sulphate                                   | Calcium sulphate                                                                                                                                                                   |

**Table 16.11 Cont'd**

| <i>Pollutant</i>       | <i>Example</i>                                            |
|------------------------|-----------------------------------------------------------|
| Sulphite liquor        | Sodium sulphite                                           |
| Suspended particles    | –                                                         |
| Total dissolved solids | Carbonate<br>Chloride<br>Nitrate<br>Phosphate<br>Sulphate |

**Table 16.12 Sensitivity of aquatic organisms to lowered pH**

| <i>pH</i> | <i>Effect</i>                                        |
|-----------|------------------------------------------------------|
| 6.0       | Crustaceans, molluscs etc. disappear                 |
|           | White moss increases                                 |
| 5.8       | Salmon, char, trout and roach die                    |
|           | Salamander eggs fail to hatch                        |
|           | Sensitive insects, phytoplankton and zooplankton die |
| 5.5       | Whitefish and grayling die                           |
| 5.0       | Perch and pike die                                   |
| 4.5       | Eels and brook trout die                             |
| 4.0       | Crickets, frogs and northern spring peepers die      |

**Table 16.13 Toxic concentrations of heavy metals to rainbow trout**

| <i>Metal</i> | <i>Concentration (mg/l) which kills half the number of exposed fish in 48 hours (LC<sub>50</sub>)</i> |                   |
|--------------|-------------------------------------------------------------------------------------------------------|-------------------|
|              | <i>Soft water</i>                                                                                     | <i>Hard water</i> |
| Copper       | 0.04                                                                                                  | 0.5               |
| Cadmium      | 0.05                                                                                                  | 5.5               |
| Zinc         | 0.5                                                                                                   | 3                 |
| Lead         | 1                                                                                                     | –                 |
| Nickel       | 15                                                                                                    | 100               |

risks to sewermen, e.g. from the generation of toxic gases such as hydrogen sulphide, to avoid obstruction of flow, e.g. from suspended solids, to eliminate any risk of explosion or fire from volatile flammable liquids, and to ensure there is no subsequent interference with waste treatment processes.

The type of consent conditions imposed, where the effluent represents only a small proportion of the flow in a sewer, are exemplified in Table 16.15.

More stringent limits are imposed upon discharges to natural waters as exemplified in Table 16.16. In both cases the BOD, the biological oxygen demand, represents the demand for oxygen in order to decompose the organics in the effluent.

## Solid wastes

Land pollution has arisen from the direct dumping of domestic and industrial solid waste, but this

**Table 16.14 Concentrations, in ppm, of substances which show toxic effects in various organisms (in river water, pH 7.5)**

|                  | <i>Bacteria—<br/>Escherichia<br/>coli</i> | <i>Green algae—<br/>Scenedesmus<br/>quadricauda</i> | <i>Daphnia<br/>magna</i> | <i>Protozoa<br/>microregma</i> |
|------------------|-------------------------------------------|-----------------------------------------------------|--------------------------|--------------------------------|
| Copper           | 0.08                                      | 0.15                                                | 0.1                      | 0.05                           |
| Zinc             | 1.4 to 2.3                                | 1 to 1.4                                            | 1.8                      | 0.33                           |
| Chromium III     |                                           | 4 to 6                                              | 42                       | 37                             |
| Cyanide          | 0.4 to 0.8                                | 0.16                                                | 0.8                      | 0.04                           |
| Cyanate          | 10                                        | 520                                                 | 23                       | 21                             |
| Sulphide         | 93                                        | 40                                                  | 26                       |                                |
| Phenol           |                                           | 40                                                  | 16                       | 30                             |
| Toluene          | 200                                       | 120                                                 | 60                       |                                |
| <i>o</i> -Xylene | 500                                       | 40                                                  | 16                       | 10                             |
| <i>m</i> -Xylene |                                           | 40                                                  | 24                       | 70                             |
| <i>p</i> -Xylene |                                           | 40                                                  | 10                       | 50                             |
| Amyl alcohol     |                                           | 280                                                 | 440                      | 20                             |
| Formic acid      |                                           | 100                                                 | 120                      |                                |
| Butyric acid     |                                           | 200                                                 | 60                       |                                |
| Butyl acetate    |                                           | 320                                                 | 44                       | 20                             |
| Amyl acetate     |                                           | 180                                                 | 120                      | 40                             |

**Table 16.15 Type of consent conditions for discharge to sewers.** (Other factors, e.g. the specific sewer, flowrate, total volume discharged, are also defined)

| <i>Parameter/substance</i>         | <i>Maximum allowed</i> |
|------------------------------------|------------------------|
| pH range                           | 6–10 (permitted range) |
| Sulphate (as SO <sub>3</sub> )     | 500–1000 mg/l          |
| Free ammonia (as NH <sub>3</sub> ) | 500 mg/l               |
| Suspended solids                   | 500–1000 mg/l          |
| Tarry and fatty matter             | 500 mg/l               |
| Sulphide (as S)                    | 10 mg/l                |
| Cyanide (as CN)                    | 10 mg/l                |
| Immiscible organic solvents        | nil                    |
| Calcium carbide                    | nil                    |
| Temperature                        | 45 C                   |
| Petroleum and petroleum spirit     | nil                    |
| Total non-ferrous metals           | 30 mg/l                |
| Soluble non-ferrous metals         | 10 mg/l                |
| Separable oil and/or grease        | 300–400 mg/l           |

is not the sole cause. It may arise from excessive application of agrochemicals, and indirect contamination resulting from leaks or from leaching of hazardous components from liquid waste disposal sites, or from atmospheric fallout. Land may also become contaminated by chemicals processed, stored or dumped at the site, perhaps in the distant past. Such contamination may pose a health risk to workers on the site, those subsequently involved in building, construction or engineering works, or the public (e.g. arising from trespass), and to animals.

Soil surveys relating to construction work require samples from at least the depth of excavation; water seepage may cause cross-contamination of land. Some guidelines for the classification of contaminated soils are summarized in Table 16.17.

**Table 16.16 Typical consent conditions for the discharge of industrial effluent to rivers and streams (UK)**

|                                                                                  | <i>Maximum allowed</i> |
|----------------------------------------------------------------------------------|------------------------|
| <b>Fishing streams</b>                                                           |                        |
| BOD (5 days at 20 °C)                                                            | 20 mg/l                |
| Suspended solids                                                                 | 30 mg/l                |
| pH                                                                               | 5–9                    |
| Sulphide, as S                                                                   | 1 mg/l                 |
| Cyanide, as CN                                                                   | 0.1 mg/l               |
| Arsenic, cadmium, chromium, copper, lead, nickel, zinc, individually or in total | 1 mg/l                 |
| Free chlorine                                                                    | 0.5 mg/l               |
| Oils and grease                                                                  | 10 mg/l                |
| Temperature                                                                      | 30 °C                  |
| <b>Non-fishing streams</b>                                                       |                        |
| BOD (5 days at 20 °C)                                                            | 40 mg/l                |
| Suspended solids                                                                 | 40 mg/l                |
| pH                                                                               | 5–9                    |
| Transparency of settled sample                                                   | ≥100 mm                |
| Sulphide, as S                                                                   | 1 mg/l                 |
| Cyanide, as CN                                                                   | 0.2 mg/l               |
| Oils and grease                                                                  | 10 mg/l                |
| Formaldehyde                                                                     | 1 mg/l                 |
| Phenols (as cresols)                                                             | 1 mg/l                 |
| Free chlorine                                                                    | 1 mg/l                 |
| Tar                                                                              | none                   |
| Toxic metals, individually or in total                                           | 1 mg/l                 |
| Soluble solids                                                                   | 7500 mg/l              |
| Temperature                                                                      | 32.5 °C                |
| Insecticides or radioactive material                                             | none                   |

## Sources

When classified in terms of handling and disposal methods, ‘solid wastes’ may comprise:

liquids, e.g. in drums, slurries, sludges, thixotropic solids, solids, as inert or ‘hazardous’ waste.

(The sources of solid wastes *per se* are summarized in Tables 16.1 and 16.4.) However, dealing with any of them will involve some combination of the activities shown in Figure 16.2, i.e. collection, segregation and identification, processing, recycling, transport and final disposal.

## Effects

The effects from solid waste treatment and disposal depend upon the specific waste and the methods employed. The major disposal methods, depending upon the quantity and nature of the waste, are:

disposal on land by landfill or land-raising;  
incineration, which requires air pollution control measures (Table 17.9) and a procedure for ash disposal; energy recovery may be practised;

**Table 16.17 Guidelines for classification of contaminated soils: suggested range of values (ppm) on air dried soils**

| <i>Parameter</i>    | <i>Typical values for uncontaminated soils</i> | <i>Slight contamination</i> | <i>Contaminated</i> | <i>Heavy contamination</i> | <i>Unusually heavy contamination</i> |
|---------------------|------------------------------------------------|-----------------------------|---------------------|----------------------------|--------------------------------------|
| pH (acid)           | 6–7                                            | 5–6                         | 4–5                 | 2–4                        | (<2)                                 |
| pH (alkaline)       | 7–8                                            | 8–9                         | 9–10                | 10–12                      | 12                                   |
| Antimony            | 0–30                                           | 30–50                       | 50–100              | 100–500                    | 500                                  |
| Arsenic             | 0–30                                           | 30–50                       | 50–100              | 100–500                    | 500                                  |
| Cadmium             | 0–1                                            | 1–3                         | 3–10                | 10–50                      | 50                                   |
| Chromium            | 0–100                                          | 100–200                     | 200–500             | 500–2500                   | 2500                                 |
| Copper (available)  | 0–100                                          | 100–200                     | 200–500             | 500–2500                   | 2500                                 |
| Lead                | 0–500                                          | 500–1000                    | 1000–2000           | 2000–1.0%                  | 1.0%                                 |
| Lead (available)    | 0–200                                          | 200–500                     | 500–1000            | 1000–5000                  | 5000                                 |
| Mercury             | 0–1                                            | 1–3                         | 3–10                | 10–50                      | 50                                   |
| Nickel (available)  | 0–20                                           | 20–50                       | 50–200              | 200–1000                   | 1000                                 |
| Zinc (available)    | 0–250                                          | 250–500                     | 500–1000            | 1000–5000                  | 5000                                 |
| Zinc (equivalent)   | 0–250                                          | 250–500                     | 500–2000            | 2000–1.0%                  | 1.0%                                 |
| Boron (available)   | 0–2                                            | 2–5                         | 5–50                | 50–250                     | 250                                  |
| Selenium            | 0–1                                            | 1–3                         | 3–10                | 10–50                      | 50                                   |
| Barium              | 0–500                                          | 500–1000                    | 1000–2000           | 2000–1.0%                  | 1.0%                                 |
| Beryllium           | 0–5                                            | 5–10                        | 10–20               | 20–50                      | 50                                   |
| Manganese           | 0–500                                          | 500–1000                    | 1000–2000           | 2000–1.0%                  | 1.0%                                 |
| Vanadium            | 0–100                                          | 100–200                     | 200–500             | 500–2500                   | 2500                                 |
| Magnesium           | 0–500                                          | 500–1000                    | 1000–2000           | 2000–1.0%                  | 1.0%                                 |
| Sulphate            | 0–2000                                         | 2000–5000                   | 5000–1.0%           | 1.0–5.0%                   | 5.0%                                 |
| Sulphur (free)      | 0–100                                          | 100–500                     | 500–1000            | 1000–5000                  | 5000                                 |
| Sulphide            | 0–10                                           | 10–20                       | 20–100              | 100–500                    | 500                                  |
| Cyanide (free)      | 0–1                                            | 1–5                         | 5–50                | 50–100                     | 100                                  |
| Cyanide             | 0–5                                            | 5–25                        | 25–250              | 250–500                    | 500                                  |
| Ferricyanide        | 0–100                                          | 100–500                     | 500–1000            | 1000–5000                  | 5000                                 |
| Thiocyanide         | 0–10                                           | 10–50                       | 50–100              | 100–500                    | 2500                                 |
| Coal tar            | 0–500                                          | 500–1000                    | 1000–2000           | 2000–1.0%                  | 1.0%                                 |
| Phenol              | 0–2                                            | 2–5                         | 5–50                | 50–250                     | 250                                  |
| Toluene extract     | 0–5000                                         | 5000–1.0%                   | 1.0–5.0%            | 5.0–25.0%                  | 25.0%                                |
| Cyclohexane extract | 0–2000                                         | 2000–5000                   | 5000–2.0%           | 2.0–10%                    | 10.0%                                |

recycling, a procedure now promoted – either by primary or secondary routes; pyrolysis – yielding useful by-products.

Any hazard which land deposition may create requires assessment with regard to the risk of injury or impairment of health to persons or animals, damage to vegetation, pollution of controlled waters including aquifers – either directly or because of water run-off, and of long-term accumulation, e.g. of heavy metals or persistent chemicals.

Landfill disposal of certain categories of solid waste may result in gas generation, mainly methane, and a highly polluted leachate. The methane may be drawn off, to avoid a flammable hazard on- or off-site. The leachate is pumped off for treatment.

A summary of the potential hazards associated with toxic waste deposition on land is given in Table 16.18.

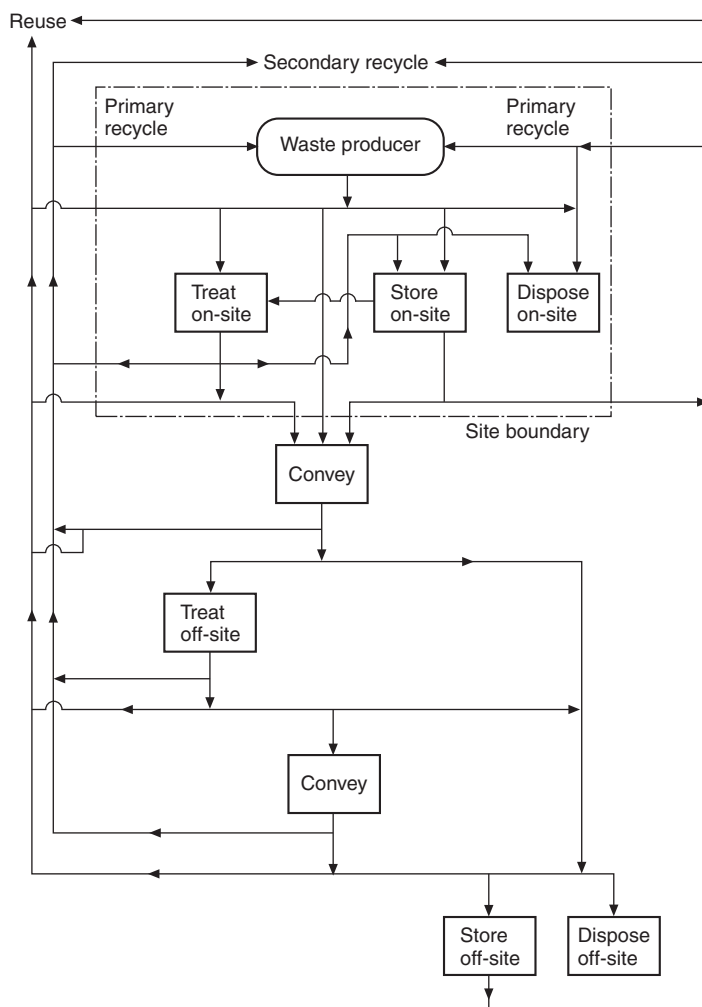


**Figure 16.2** Three basic techniques – treatment, storage, conveyance – to effect recycle or disposal of ‘solid’ waste either on- or off-site.

**Table 16.18** Potential hazards from toxic waste deposition

|                        |                                                                                                                                                                                                          |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Air pollution</b>   | Dust, effluvia, smoke and fume, odour                                                                                                                                                                    |
| <b>Land pollution</b>  | Toxic or flammable gas generation<br>Gross amenity damage<br>Undermining of site stability<br>Sterilization of surrounding land due to heavy metals<br>pH changes etc.<br>Permanent ‘land contamination’ |
| <b>Water pollution</b> | Deposited material or percolate escapes either by surface run-off or by underground movement, threatening streams, rivers, aquifers or the sea<br>Direct ‘poisoning’ or eutrophication                   |

# Chemicals and the environment: monitoring and protection

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## Legislative control

Comprehensive pollution control legislation exists in most developed countries and there is increasing conformity within the EC.

### *The Environmental Protection Act (EPA) 1990*

In the UK the Environmental Protection Act 1990 established an interlocking framework for pollution control. Integrated Pollution Control (IPC) introduced a new approach with waste minimization at its centre and a commitment to higher environmental standards. The latter is based upon selection of the Best Practical Environmental Option (BPEO), i.e.:

the option which in the context of releases from a prescribed process, provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as the short term.

The reform of waste disposal aims to minimize waste generation and maximize recycling.

Under Part 1 of EPA 90, an IPC system controls emissions to air, land and water for the most polluting industrial and similar processes. All operators of prescribed processes, e.g. fuel and power, minerals, waste disposal and chemical, require prior authorization. They are required to use BATNEEC, the Best Available Technology Not Entailing Excessive Cost:

for preventing the release of substances prescribed for any environmental medium, or where that is not practicable by such means;  
for reducing the release of such substances to a minimum and for rendering harmless any such substances which are released;  
for rendering harmless any other substances which might cause harm if released into any environmental medium.

Any authorization may contain specific conditions with details on how BATNEEC is to be achieved, e.g.:

the mode of operation of the plant; the pollution abatement technology to be used; and, explicit limits on the amount and concentration of substances which may be discharged.

Some aspects of the process may not be covered explicitly by conditions, but there remains a residual duty on the operator to prevent or minimize the release of prescribed substances by the use of BATNEEC.

Local authority control of air pollution covers a second tier of less-polluting processes. Incinerators for waste chemicals, or waste plastic arising from their manufacture, and other waste incinerators dependent upon size are, however, subject to both the BATNEEC and BPEO requirements under the IPC regime.

Any IPC application will include, in addition to details of the operator:

A description of the prescribed process.

A list of prescribed substances, and other substances which are potentially environmentally harmful, used in or resulting from the process. The quantities that might be released with control technologies in place.

Details of any proposed release of prescribed substances and an assessment of the environmental consequences of emissions. (For local authorities air pollution controlled processes this applies only to atmospheric emissions.)

Information to show that BATNEEC is to be applied; a description of techniques for preventing, minimizing and rendering harmless the emissions. How these techniques will be monitored.

Proposals for monitoring the release of such substances and the environmental consequences.

It must include an assessment to demonstrate that the process represents the BPEO.

Part II of EPA 90 deals with waste disposal, handling and management. The provisions impose duties on the producers of waste to ensure the safe disposal. There are strong licensing powers for local authorities, with continuing responsibilities for licensees to monitor and maintain sites after closure.

The Clean Air Act 1993 provides a comprehensive control mechanism for the protection of the environment from smoke, dust and fumes. The 1993 Act consolidates the previous provisions of the 1956 and 1968 Clean Air Acts.

Section 1 of the Act prohibits:

dark smoke emissions from a chimney of any building

dark smoke emissions from a chimney serving the furnace of a fixed boiler or industrial plant.

The Dark Smoke (Permitted Periods) Regulations, give details on circumstances and time limits when dark smoke is allowed.

Section 2 of this Act prohibits dark smoke from any industrial or trade premises (there is no requirement under Section 2 for the dark smoke to be emitted from a chimney).

### ***The Water Industry Act 1991 and Water Resources Act 1991***

The disposal of aqueous-based wastes, i.e. liquid effluents, is regulated in part by the Water Industry Act 1991 and the Water Resources Act 1991.

The discharge of any trade effluent into a public sewer requires a specific consent from the sewerage undertaker. If granted, conditions are attached to the consent relating to which sewer, flowrates and composition (see Table 16.15), metering of flowrate, and possibly automatic monitoring. For Special Category Effluents, e.g. mercury, pesticides, chlorinated organics, as listed in Schedule 1 of the Trade Effluents (Prescribed Processes and Substances) Regulations 1989 (Table 17.1), agreement must also be obtained from the Environment Agency.



Discharge to 'controlled waters' is controlled under the Water Resources Act 1991. These waters are defined and generally include territorial waters, coastal waters, inland waters and ground water. If the discharge is from a prescribed process, and of a prescribed substance under the Environmental Protection Act 1990, consent for discharge is required under an IPC authorization. All other discharges require consent from the Environment Agency under the Water Resources Act. Such consent is subject to conditions as to composition, flowrate, measures to minimize pollution, etc. A specimen consent form is given in Figure 17.1. Schedule 5 of the regulations details the prescribed substances (Red List). Where a discharge contains more than the stated amount of a prescribed substance (Table 17.2) it cannot be released to water without an authorization from the Environment Agency.

| <b>NATIONAL RIVERS AUTHORITY</b><br><b>WATER RESOURCES ACT 1991 – CONSENT TO DISCHARGE</b>                                                                                                                   |  |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| Reference number .....                                                                                                                                                                                       |  |
| <p>The National Rivers Authority, in pursuance of its powers under the above mentioned Act, HEREBY GIVES CONSENT to the discharge described hereunder subject to the terms and conditions set out below.</p> |  |
| Name and Address of Applicant: .....                                                                                                                                                                         |  |
| Date of Application: .....                                                                                                                                                                                   |  |
| Date of Consent: .....                                                                                                                                                                                       |  |
| Description of discharge: .....                                                                                                                                                                              |  |
| Type: .....                                                                                                                                                                                                  |  |
| From: .....                                                                                                                                                                                                  |  |
| To: .....                                                                                                                                                                                                    |  |
| National Grid Reference of Discharge Point: .....                                                                                                                                                            |  |
| <p>This consent shall not be taken as providing a statutory defence against a charge of pollution in respect of any poisonous, noxious or polluting constituents not specified herein.</p> <p>.....</p>      |  |
| <b>Conditions</b>                                                                                                                                                                                            |  |
| 1. General<br>2. As to Outlet<br>3. As to Volume Discharged to watercourse<br>4. As to Discharge composition                                                                                                 |  |
| NRA Region: .....                                                                                                                                                                                            |  |
|                                                                                                                                                                                                              |  |
|                                                                                                                                                                                                              |  |
| NRA Authorized Signature: .....                                                                                                                                                                              |  |

**Figure 17.1** *Typical consent form*

**Table 17.1 Prescribed substances**


---

|                                                       |
|-------------------------------------------------------|
| Aldrin, dieldrin, endrin and isodrin                  |
| Arsenic                                               |
| Atrazine                                              |
| Azinphos-ethyl                                        |
| Azinphos-methyl                                       |
| Boron                                                 |
| Cadmium and its compounds                             |
| Carbon tetrachloride                                  |
| Chloroform                                            |
| Chromium                                              |
| Copper                                                |
| Cyanide                                               |
| Cyfluthrin                                            |
| DDT                                                   |
| 1,2-Dichloroethane                                    |
| Dichlorvos                                            |
| Dioxins                                               |
| Endosulfan                                            |
| Fenitrothion                                          |
| Fenthion                                              |
| Fluocifuron                                           |
| Hexachlorobenzene (HCB)                               |
| Hexachlorobutadiene (HCBD)                            |
| Hexachlorocyclohexane (Lindane and related compounds) |
| Iron                                                  |
| Lead                                                  |
| Malathion                                             |
| Mercury and its compounds                             |
| Nickel                                                |
| Parathion                                             |
| Parathion-methyl                                      |
| PCSDs                                                 |
| Pentachlorophenol (PCP)                               |
| Perchloroethylene                                     |
| Permethrin                                            |
| pH outside the range 5.5 to 9.0                       |
| Polychlorinated biphenyls                             |
| Simazine                                              |
| Sulcofuron                                            |
| Tetrachloroethylene                                   |
| Tributyltin compounds                                 |
| Trichlorobenzene                                      |
| Trichloroethane                                       |
| Trichloroethylene                                     |
| Trifluralin                                           |
| Triphenyltin compounds                                |
| Vanadium                                              |
| Zinc                                                  |

---

Whereas the Red List was produced by the UK government in 1989, and includes the most harmful and polluting substances, the EC in Directive 76/464/EEC introduced Black and Grey Lists, referred to in the Directive as Lists 1 and 2, respectively. National governments are required to eliminate pollution by the substances blacklisted and to reduce pollution by those in the Grey List. The 129 substances in the Black List were selected mainly on the basis of their toxicity, persistence and accumulation in living organisms and in sediment. They are generally considered to be more dangerous than those on the Grey List and are to be controlled by authorization in

**Table 17.2 The Red List maximum discharge levels above which prior authorization is required**

| <i>Prescribed substances</i>         | <i>Amount released above background in any 12 month period (grams)</i> |
|--------------------------------------|------------------------------------------------------------------------|
| Mercury and its compounds            | 200 (expressed as metal)                                               |
| Cadmium and its compounds            | 1000 (expressed as metal)                                              |
| All isomers of hexachlorocyclohexane | 20                                                                     |
| All isomers of DDT                   | 5                                                                      |
| Pentachlorophenol and its compounds  | 350 (expressed as PCP)                                                 |
| Hexachlorobenzene                    | 5                                                                      |
| Hexachlorobutadiene                  | 20                                                                     |
| Aldrin                               | 2                                                                      |
| Dieldrin                             | 2                                                                      |
| Endrin                               | 1                                                                      |
| Polychlorinated biphenyls (PCBs)     | 1                                                                      |
| Dichlorvos                           | 0.2                                                                    |
| 1,2-Dichloroethane                   | 2000                                                                   |
| All isomers of trichlorobenzene      | 75                                                                     |
| Atrazine*                            | 350                                                                    |
| Simazine*                            | 350                                                                    |
| Tributyltin compounds                | 4 (expressed as TBT)                                                   |
| Triphenyltin compounds               | 4 (expressed as TPT)                                                   |
| Trifluralin                          | 20                                                                     |
| Fenitrothion                         | 2                                                                      |
| Azinphos-methyl                      | 2                                                                      |
| Malathion                            | 2                                                                      |
| Endosulfan                           | 0.5                                                                    |

\* Where both atrazine and simazine are released, the figure in aggregate is 350 grams.

accordance with European Community limit values or quality objectives to be set in daughter Directives on specific substances. They can be divided into the families shown in Table 17.3. The Grey List comprises the families of materials shown in Table 17.4. The contents of the Grey List may be added to the Black List in due course, and may thus be subject to the same tight controls.

Pesticides are also one of the main sources of inland water pollution and the EC has set limits for pesticide levels in surface waters. Most pesticides in surface waters come from diffuse losses soon after spraying. High levels of other specific pesticides often result from farmyard spillages. Any person using a pesticide must take all reasonable precautions to protect the health of human beings, creatures and plants, to safeguard the environment, and in particular to avoid pollution of water. They should be given instruction, training and guidance in the safe, efficient and humane use of pesticides and be competent in the duties they are called upon to perform. They are not permitted to combine or mix two or more pesticides nor use a pesticide in conjunction with an

**Table 17.3 The Black List substances prohibited from discharge to ground water**

|                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------|
| Organohalogenated compounds and substances which may form such compounds in the aquatic environment                    |
| Organophosphorus compounds                                                                                             |
| Organotin compounds                                                                                                    |
| Substances which possess carcinogenic properties                                                                       |
| Mercury and its compounds                                                                                              |
| Cadmium and its compounds                                                                                              |
| Persistent mineral oils and hydrocarbons of petroleum origin                                                           |
| Persistent synthetic substances which may float, remain in suspension or sink and interfere with any use of the waters |

**Table 17.4 The Grey List substances for which authorization is required prior to discharge**


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|                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Biocides and their derivatives not appearing in the black list                                                                                  |
| Substances which have a deleterious effect on the taste and/or smell of the products for human consumption derived from the aquatic environment |
| Toxic or persistent organic compounds of silicon                                                                                                |
| Inorganic compounds of phosphorus and elemental phosphorus                                                                                      |
| Non-persistent mineral oils and hydrocarbons of petroleum origin                                                                                |
| Cyanides, fluorides                                                                                                                             |
| Substances which have an adverse effect on the oxygen balance, particularly ammonia, nitrates                                                   |
| The following metalloids and metals and their compounds:                                                                                        |
| Antimony                                                                                                                                        |
| Arsenic                                                                                                                                         |
| Barium                                                                                                                                          |
| Beryllium                                                                                                                                       |
| Boron                                                                                                                                           |
| Chromium                                                                                                                                        |
| Cobalt                                                                                                                                          |
| Copper                                                                                                                                          |
| Lead                                                                                                                                            |
| Molybdenum                                                                                                                                      |
| Nickel                                                                                                                                          |
| Selenium                                                                                                                                        |
| Silver                                                                                                                                          |
| Tellurium                                                                                                                                       |
| Thallium                                                                                                                                        |
| Tin                                                                                                                                             |
| Titanium                                                                                                                                        |
| Uranium                                                                                                                                         |
| Vanadium                                                                                                                                        |
| Zinc                                                                                                                                            |

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adjuvant except under authorized circumstances. A list of pesticides and pesticide residues as defined by EC Directive 90/642/EEC as amended by 94/30/EC is given in Table 17.5. Limits are to be set by subsequent Directives in due course.

## Waste management

Under the EPA 90 a person shall not:

deposit 'controlled waste', or knowingly cause or permit its deposit;  
treat, keep or dispose of controlled waste or permit it, etc.;

except under, and in accordance with, a waste management licence. Controlled waste is household, industrial, commercial or any such waste.

Extra duties are imposed on the producers of 'Special Waste', i.e. a waste that is on the European Hazardous Waste list reproduced in Table 17.6 and if it has one or more of the hazardous properties listed in Table 17.7 (reproduced from Part 2 of Schedule 2 of the Special Waste Regulations, 1996). Also Special Waste is any Controlled Waste which has one of the listed properties. Extra requirements are detailed for the safe transfer and management of such waste.

Section 34 of EPA 90 imposes a 'cradle to grave' philosophy for waste management. This places a duty of care upon anyone who has 'control' of controlled waste, i.e. importers, producers,

**Table 17.5 Pesticides and pesticide residues**

| <i>Pesticide</i>            | <i>Residue</i>                                                                                                                                                                                           |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Aldrin and dieldrin         | singly or combined, expressed as dieldrin (HEOD)                                                                                                                                                         |
| 2-Aminobutane               | 2-aminobutane                                                                                                                                                                                            |
| Aminotriazole               | aminotriazole                                                                                                                                                                                            |
| Azinphos-methyl             | sum of azinphos-methyl and azinphos-ethyl                                                                                                                                                                |
| Bitertanol                  | bitertanol                                                                                                                                                                                               |
| Captafol                    | captafol                                                                                                                                                                                                 |
| Captan                      | sum of captan and folpet                                                                                                                                                                                 |
| Carbaryl                    | carbaryl                                                                                                                                                                                                 |
| Carbendazim                 | carbendazim (from use of benomyl, thiophanate-methyl and carbendazim)                                                                                                                                    |
| Carbon disulphide           | carbon disulphide                                                                                                                                                                                        |
| Carbon tetrachloride        | carbon tetrachloride                                                                                                                                                                                     |
| Carbophenothion             | sum of carbophenothion, its sulfoxide and its sulphone, expressed as carbophenothion                                                                                                                     |
| Chlordane                   | (1) for products of animal origin: sum of cis- and trans-isomers and oxychlordane expressed as chlordane;<br>(2) for cereals, fruit and vegetables: sum of cis- and trans-isomers expressed as chlordane |
| Chlorfenvinphos             | sum of E- and Z-isomers of chlorfenvinphos                                                                                                                                                               |
| Chlorpyrifos-methyl         | chlorpyrifos-methyl                                                                                                                                                                                      |
| DDT                         | sum of pp'-DDT, op'-DDT, pp'-TDE and pp'-DDE expressed as DDT                                                                                                                                            |
| Diazinon                    | diazinon                                                                                                                                                                                                 |
| 1,2-Dibromoethane           | 1,2-dibromoethane                                                                                                                                                                                        |
| Dichlofluanid               | dichlofluanid                                                                                                                                                                                            |
| Dichlorvos                  | dichlorvos                                                                                                                                                                                               |
| Dicofol                     | Dicofol                                                                                                                                                                                                  |
| Diiflubenzuron              | diiflubenzuron                                                                                                                                                                                           |
| Dimethipin                  | dimethipin                                                                                                                                                                                               |
| Dimethoate                  | dimethoate                                                                                                                                                                                               |
| Dithiocarbamates            | alkylenbisdithiocarbamates and alkylthiuramdisulphides and dialkyldithiocarbamates determined and expressed as carbon disulphide (CS <sub>2</sub> )                                                      |
| Endosulfan                  | sum of alpha- and beta-isomers and of endosulfan sulphate, expressed as endosulfan                                                                                                                       |
| Endrin                      | endrin                                                                                                                                                                                                   |
| Ethion                      | ethion                                                                                                                                                                                                   |
| Etrifos                     | sum of etrimfos, its oxygen analogue and 6-ethoxy-2-ethyl-4-hydroxypyrimidine                                                                                                                            |
| Fenitrothion                | fenitrothion                                                                                                                                                                                             |
| Fluazifop                   | fluazifop and esters (including conjugates) of haloxyfop, expressed as free acid                                                                                                                         |
| Fluorochloridone            | fluorochloridone                                                                                                                                                                                         |
| Haloxyfop                   | haloxyfop and esters (including conjugates) of haloxyfop, expressed as free acid                                                                                                                         |
| Hexachlorobenzene (HCB)     | hexachlorobenzene                                                                                                                                                                                        |
| Hexachlorocyclohexane (HCH) | hexachlorocyclohexane<br>alpha-isomer<br>beta-isomer<br>gamma-isomer                                                                                                                                     |
| Heptachlor                  | sum of heptachlor and heptachlor epoxide, expressed as heptachlor                                                                                                                                        |
| Hydrogen cyanide            | cyanides expressed as hydrogen cyanide                                                                                                                                                                   |
| Hydrogen phosphide          | phosphides expressed as hydrogen phosphide                                                                                                                                                               |
| Imazalil                    | imazalil                                                                                                                                                                                                 |
| Inorganic bromide           | determined and expressed as total bromine from all sources                                                                                                                                               |
| Ioxynil                     | ioxynil                                                                                                                                                                                                  |
| Iprodione                   | sum of iprodione and all metabolites containing 3,5-dichloroaniline moiety, expressed as iprodione                                                                                                       |
| Malathion                   | sum of malathion and malaoxon, expressed as malathion                                                                                                                                                    |
| Mercury compounds           | determined as total mercury and expressed as mercury                                                                                                                                                     |
| Methacrifos                 | methacrifos                                                                                                                                                                                              |
| Methyl bromide              | bromomethane                                                                                                                                                                                             |
| Mevinphos                   | sum of cis- and trans-mevinphos                                                                                                                                                                          |

Table 17.5 Cont'd

| <i>Pesticide</i>  | <i>Residue</i>                                                                                                    |
|-------------------|-------------------------------------------------------------------------------------------------------------------|
| Omethoate         | omethoate (from use of formothion, demethoate and omethoate)                                                      |
| Parathion         | parathion                                                                                                         |
| Parathion-methyl  | parathion-methyl                                                                                                  |
| Phosalone         | phosalone                                                                                                         |
| Phosphamidon      | sum of phosphamidon (E- and Z-isomers) and N<br>desethylphosphamidon (E- and Z-isomers) expressed as phosphamidon |
| Pirimiphos-methyl | pirimiphos-methyl                                                                                                 |
| Pyrethrins        | sum of pyrethrins I and II, cinerins I and II, jasmolins I and II                                                 |
| Quintozene        | sum of quintozone, pentachloroaniline and methyl pentachlorophenylsulphide expressed<br>as quintozone             |
| Tecnazene         | tecnazene                                                                                                         |
| Thiabendazole     | thiabendazole                                                                                                     |
| Triazophos        | triazophos                                                                                                        |
| Trichlorfon       | trichlorfon                                                                                                       |
| 2,4,5-T           | 2,4,5-T                                                                                                           |
| Vinclozolin       | sum of vinclozolin and all metabolites containing 3,5-dichloroaniline moiety, expressed<br>as vinclozolin         |

carriers, keepers, treaters, disposers, recyclers and brokers. They are required to take all such measures as are reasonable in the circumstances:

- to prevent any person from contravening EPA 90, i.e. the prohibition placed upon unauthorized or harmful deposition, treatment or disposal of waste;
- to prevent the escape of waste; and
- on transfer, to secure that it is only to an authorized person, or for authorized transport, and with an adequate written description of the waste.

Duty of Care Regulations outline a transfer note system from which the Environment Agency can trace the destination of waste and previous holders. The information required on a transfer note is illustrated in Figure 17.2. In order to comply with the statutory duty of care in respect of waste the following procedures are advised in a Code of Practice:

Identify and describe the waste:

- Is it controlled waste?
- What problems are associated with the waste and its disposal?
- What should be included in the description?

Keep the waste safely:

- Are containers secure for both storage and transit?
- What precautions have been taken to ensure security of waste?

Transfer to the right person:

- Will public authorities take the waste?
- Is the carrier registered, or exempt from registration (under the Control of Pollution (Amendment) Act 1989 and the Controlled Waste (Registration of Carriers and Seizures of Vehicles) Regulations 1991)?
- Is the waste manager properly licensed?

Steps on receiving waste:

- Who did the waste come from?
- Does the waste tally with its description?
- Are proper records being kept?

**Table 17.6 European Hazardous Waste List**

| <i>Code</i> | <i>Description</i>                                                                                                                                         |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 02          | Waste from agricultural, horticultural, hunting, fishing and aquaculture primary production, food preparation and processing                               |
| 03          | Wastes from wood processing and the production of paper, cardboard, pulp, panels and furniture                                                             |
| 04          | Wastes from the leather and textile industries                                                                                                             |
| 05          | Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal                                                                   |
| 06          | Wastes from inorganic chemical processes                                                                                                                   |
| 07          | Wastes from organic chemical processes                                                                                                                     |
| 08          | Wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes and vitreous enamels), adhesive, sealants and printing inks |
| 09          | Wastes from the photographic industry                                                                                                                      |
| 10          | Inorganic wastes from thermal processes                                                                                                                    |
| 11          | Inorganic waste with metals from metal treatment and the coating of metals; non-ferrous hydro-metallurgy                                                   |
| 12          | Wastes from shaping and surface treatment of metals and plastics                                                                                           |
| 13          | Oil wastes (except edible oils, 0500 and 1200)                                                                                                             |
| 14          | Wastes from organic substances employed as solvents (except 0700 and 0800)                                                                                 |
| 16          | Wastes not otherwise specified in the catalogue                                                                                                            |
| 17          | Construction and demolition waste (including road construction)                                                                                            |
| 18          | Wastes from human or animal health care and/or related research (excluding kitchen and restaurant wastes which do not arise from immediate health care)    |
| 19          | Wastes from waste treatment facilities, off-site waste water treatment plants and the water industry                                                       |
| 20          | Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions                                      |
| 02          | Waste from agricultural, horticultural, hunting, fishing and aquaculture primary production, food preparation and processing                               |
|             | 0201 primary production waste                                                                                                                              |
|             | 020105 agrochemical wastes                                                                                                                                 |
| 03          | Wastes from wood processing and the production of paper, cardboard, pulp, panels and furniture                                                             |
|             | 0302 wood preservation waste                                                                                                                               |
|             | 030201 non-halogenated organic wood preservatives                                                                                                          |
|             | 030202 organochlorinated wood preservatives                                                                                                                |
|             | 030203 organometallic wood preservatives                                                                                                                   |
|             | 030204 inorganic wood preservatives                                                                                                                        |
| 04          | Wastes from the leather and textile industries                                                                                                             |
|             | 0401 wastes from the leather industry                                                                                                                      |
|             | 040103 degreasing wastes containing solvents without a liquid phase                                                                                        |
|             | 0402 wastes from textile industry                                                                                                                          |
|             | 040211 halogenated wastes from dressing and finishing                                                                                                      |
| 05          | Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal                                                                   |
|             | 0501 oily sludges and solid wastes                                                                                                                         |
|             | 050103 tank bottom sludges                                                                                                                                 |
|             | 050104 acid alkyl sludges                                                                                                                                  |
|             | 050105 oil spills                                                                                                                                          |
|             | 050107 acid tars                                                                                                                                           |
|             | 050108 other tars                                                                                                                                          |
|             | 0504 spent filter clays                                                                                                                                    |
|             | 050401 spent filter clays                                                                                                                                  |
|             | 0506 waste from the pyrolytic treatment of coal                                                                                                            |
|             | 050601 acid tars                                                                                                                                           |
|             | 050603 other tars                                                                                                                                          |
|             | 0507 waste from natural gas purification                                                                                                                   |
|             | 050701 sludges containing mercury                                                                                                                          |
|             | 0508 wastes from oil regeneration                                                                                                                          |
|             | 050801 spent filter clays                                                                                                                                  |
|             | 050802 acid tars                                                                                                                                           |
|             | 050803 other tars                                                                                                                                          |
|             | 050804 aqueous liquid waste from oil regeneration                                                                                                          |
| 06          | Wastes from inorganic chemical processes                                                                                                                   |
|             | 0601 waste acidic solutions                                                                                                                                |

Table 17.6 Cont'd

| <i>Code</i> | <i>Description</i>                                                                        |
|-------------|-------------------------------------------------------------------------------------------|
| 060101      | sulphuric acid and sulphurous acid                                                        |
| 060102      | hydrochloric acid                                                                         |
| 060103      | hydrofluoric acid                                                                         |
| 060104      | phosphoric and phosphorus acid                                                            |
| 060105      | nitric acid and nitrous acid                                                              |
| 060199      | waste not otherwise specified                                                             |
| 0602        | alkaline solutions                                                                        |
| 060201      | calcium hydroxide                                                                         |
| 060202      | soda                                                                                      |
| 060203      | ammonia                                                                                   |
| 060299      | wastes not otherwise specified                                                            |
| 0603        | waste salts and their solutions                                                           |
| 060311      | salts and solutions containing cyanides                                                   |
| 0604        | metal-containing wastes                                                                   |
| 060402      | metallic salts (except 0603)                                                              |
| 060403      | wastes containing arsenic                                                                 |
| 060404      | wastes containing mercury                                                                 |
| 060405      | wastes containing heavy metals                                                            |
| 0607        | wastes from halogen chemical processes                                                    |
| 060701      | wastes containing asbestos from electrolysis                                              |
| 060702      | activated carbon from chlorine production                                                 |
| 0613        | wastes from other inorganic chemical processes                                            |
| 061301      | inorganic pesticides, biocides and wood preserving agents                                 |
| 061302      | spent activated carbon (except 060702)                                                    |
| 07          | Wastes from organic chemical processes                                                    |
| 0701        | waste from the manufacture, formulation, supply and use (MFSU) of basic organic chemicals |
| 070101      | aqueous washing liquids and mother liquors                                                |
| 070103      | organic halogenated solvents, washing liquids and mother liquors                          |
| 070104      | other organic solvents, washing liquids and mother liquors                                |
| 070107      | halogenated still bottoms and reaction residues                                           |
| 070108      | other still bottoms and reaction residues                                                 |
| 070109      | halogenated filter cakes, spent absorbents                                                |
| 070110      | other filter cakes, spent absorbents                                                      |
| 0702        | waste from the MFSU of plastics, synthetic rubber and man-made fibres                     |
| 070201      | aqueous washing liquids and mother liquors                                                |
| 070203      | organic halogenated solvents, washing liquids and mother liquors                          |
| 070204      | other organic solvents, washing liquids and mother liquors                                |
| 070207      | halogenated still bottoms and reaction residues                                           |
| 070208      | other still bottoms and reaction residues                                                 |
| 070209      | halogenated filter cakes, spent absorbents                                                |
| 070210      | other filter cakes, spent absorbents                                                      |
| 0703        | waste from the MFSU for organic dyes and pigments (excluding 0611)                        |
| 070301      | aqueous washing liquids and mother liquors                                                |
| 070303      | organic halogenated solvents, washing liquids and mother liquors                          |
| 070304      | other organic solvents, washing liquids and mother liquors                                |
| 070307      | halogenated still bottoms and reaction residues                                           |
| 070308      | other still bottoms and reaction residues                                                 |
| 070309      | halogenated filter cakes, spent absorbents                                                |
| 070310      | other filter cakes, spent absorbents                                                      |
| 0704        | waste from the MFSU for organic pesticides (except 020105)                                |
| 070401      | aqueous washing liquids and mother liquors                                                |
| 070403      | organic halogenated solvents, washing liquids and mother liquors                          |
| 070404      | other organic solvents, washing liquids and mother liquors                                |
| 070407      | halogenated still bottoms and reaction residues                                           |
| 070408      | other still bottoms                                                                       |
| 070409      | halogenated filter cakes, spent absorbents                                                |
| 070410      | other filter cakes, spent absorbents                                                      |



Table 17.6 Cont'd

| <i>Code</i> | <i>Description</i>                                                                                                                                         |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0705        | waste from the MFSU of pharmaceuticals                                                                                                                     |
| 070501      | aqueous washing liquids and mother liquors                                                                                                                 |
| 070503      | organic halogenated solvents, washing liquids and mother liquors                                                                                           |
| 070504      | other organic solvents, washing liquids and mother liquors                                                                                                 |
| 070507      | halogenated still bottoms and reaction residues                                                                                                            |
| 070508      | other still bottoms                                                                                                                                        |
| 070509      | halogenated filter cakes, spent absorbents                                                                                                                 |
| 070510      | other filter cakes, spent absorbents                                                                                                                       |
| 0706        | waste from the MFSU of fats, grease, soaps, detergents, disinfectants and cosmetics                                                                        |
| 070601      | aqueous washing liquids and mother liquors                                                                                                                 |
| 070603      | organic halogenated solvents, washing liquids and mother liquors                                                                                           |
| 070604      | other organic solvents, washing liquids and mother liquors                                                                                                 |
| 070607      | halogenated still bottoms and reaction residues                                                                                                            |
| 070608      | other still bottoms                                                                                                                                        |
| 070609      | halogenated filter cakes, spent absorbents                                                                                                                 |
| 070610      | other filter cakes, spent absorbents                                                                                                                       |
| 0707        | waste from the MFSU of fine chemicals and chemical products                                                                                                |
| 070701      | aqueous washing liquids and mother liquors                                                                                                                 |
| 070703      | organic halogenated solvents, washing liquids and mother liquors                                                                                           |
| 070704      | other organic solvents, washing liquids and mother liquors                                                                                                 |
| 070707      | halogenated still bottoms and reaction residues                                                                                                            |
| 070708      | other still bottoms                                                                                                                                        |
| 070709      | halogenated filter cakes, spent absorbents                                                                                                                 |
| 070710      | other filter cakes, spent absorbents                                                                                                                       |
| 08          | Wastes from the manufacture, formulation, supply and use (MFSU) of coatings (paints, varnishes and vitreous enamels), adhesive, sealants and printing inks |
| 0801        | wastes from MFSU of paint and varnish                                                                                                                      |
| 080101      | waste paints and varnish containing halogenated solvents                                                                                                   |
| 080102      | waste paints and varnish free of halogenated solvents                                                                                                      |
| 080106      | sludges from paint or varnish removal containing halogenated solvents                                                                                      |
| 080107      | sludges from paint or varnish removal free of halogenated solvents                                                                                         |
| 0803        | wastes from MFSU of printing inks                                                                                                                          |
| 080301      | waste ink containing halogenated solvents                                                                                                                  |
| 080302      | waste ink free of halogenated solvents                                                                                                                     |
| 080305      | ink sludges containing halogenated solvents                                                                                                                |
| 080306      | ink sludges free of halogenated solvents                                                                                                                   |
| 0804        | wastes from MFSU of adhesive and sealants (including water-proofing products)                                                                              |
| 080401      | waste adhesives and sealants containing halogenated solvents                                                                                               |
| 080402      | waste adhesives and sealants free of halogenated solvents                                                                                                  |
| 080405      | adhesives and sealants sludges containing halogenated solvents                                                                                             |
| 080406      | adhesives and sealants sludges free of halogenated solvents                                                                                                |
| 09          | Wastes from the photographic industry                                                                                                                      |
| 09101       | wastes from the photographic industry                                                                                                                      |
| 09101       | water-based developer and activator solutions                                                                                                              |
| 09102       | water-based offset plate developer solutions                                                                                                               |
| 09103       | solvent-based developer solutions                                                                                                                          |
| 09104       | fixer solutions                                                                                                                                            |
| 09105       | bleach solutions and bleach fixer solutions                                                                                                                |
| 09106       | waste containing silver from on-site treatment of photographic waste                                                                                       |
| 10          | Inorganic wastes from thermal processes                                                                                                                    |
| 1001        | wastes from power station and other combustion plants (except 1900)                                                                                        |
| 100104      | oil fly ash                                                                                                                                                |
| 100109      | sulphuric acid                                                                                                                                             |
| 1003        | wastes from aluminium thermal metallurgy                                                                                                                   |
| 100301      | tars and other carbon-containing wastes from anode manufacture                                                                                             |
| 100303      | skimmings                                                                                                                                                  |
| 100304      | primary smelting slags/white drosses                                                                                                                       |

Table 17.6 Cont'd

| <i>Code</i> | <i>Description</i>                                                                                                                                                                      |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 100307      | spent pot lining                                                                                                                                                                        |
| 100308      | salt slags from secondary smelting                                                                                                                                                      |
| 100309      | black drosses from secondary smelting                                                                                                                                                   |
| 100310      | waste from treatment of salt slags and black drosses treatment                                                                                                                          |
| 1004        | wastes from lead thermal metallurgy                                                                                                                                                     |
| 100401      | slags (1st and 2nd smelting)                                                                                                                                                            |
| 100402      | dross and skimmings (1st and 2nd smelting)                                                                                                                                              |
| 100403      | calcium arsenate                                                                                                                                                                        |
| 100404      | flue gas dust                                                                                                                                                                           |
| 100405      | other particulates and dust                                                                                                                                                             |
| 100406      | solid waste from gas treatment                                                                                                                                                          |
| 100407      | sludges from gas treatment                                                                                                                                                              |
| 1005        | wastes from zinc thermal metallurgy                                                                                                                                                     |
| 100501      | slags (1st and 2nd smelting)                                                                                                                                                            |
| 100502      | dross and skimmings (1st and 2nd smelting)                                                                                                                                              |
| 100503      | flue gas dust                                                                                                                                                                           |
| 100505      | solid waste from gas treatment                                                                                                                                                          |
| 100506      | sludges from gas treatment                                                                                                                                                              |
| 1006        | wastes from copper thermal metallurgy                                                                                                                                                   |
| 100603      | flue gas dust                                                                                                                                                                           |
| 100605      | waste from electrolytic refining                                                                                                                                                        |
| 100606      | solid waste from gas treatment                                                                                                                                                          |
| 100607      | sludges from gas treatment                                                                                                                                                              |
| 11          | Inorganic waste with metals from metal treatment and the coating of metals; non-ferrous hydro-metallurgy                                                                                |
| 1101        | liquid wastes and sludges from metal treatment and coating of metals (e.g. galvanic processes, zinc coating processes, pickling processes, etching, phosphatizing, alkaline degreasing) |
| 110101      | cyanidic (alkaline) wastes containing heavy metals other than chromium                                                                                                                  |
| 110103      | cyanidic (alkaline) wastes which do not contain heavy metals                                                                                                                            |
| 110104      | cyanidic-free wastes containing chromium                                                                                                                                                |
| 110105      | acidic pickling solutions                                                                                                                                                               |
| 110106      | acids not otherwise specified                                                                                                                                                           |
| 110107      | alkalis not otherwise specified                                                                                                                                                         |
| 110108      | phosphatizing sludges                                                                                                                                                                   |
| 1102        | wastes and sludges from non-ferrous hydrometallurgical processes                                                                                                                        |
| 110202      | sludges from zinc hydrometallurgy (including jarosite, goethite)                                                                                                                        |
| 1103        | sludges and solids from tempering processes                                                                                                                                             |
| 110301      | wastes containing cyanide                                                                                                                                                               |
| 110302      | other wastes                                                                                                                                                                            |
| 12          | Wastes from shaping and surface treatment of metals and plastics                                                                                                                        |
| 1201        | wastes from shaping (including forging, welding, pressing, drawing, turning, cutting and filing)                                                                                        |
| 120106      | waste machining oils containing halogens (not emulsified)                                                                                                                               |
| 120107      | waste machining oils free of halogens (not emulsified)                                                                                                                                  |
| 120108      | waste machining emulsions containing halogens                                                                                                                                           |
| 120109      | waste machining emulsions free of halogens                                                                                                                                              |
| 120110      | synthetic machining oils                                                                                                                                                                |
| 120111      | machining sludges                                                                                                                                                                       |
| 120112      | spent waxes and fats                                                                                                                                                                    |
| 1203        | wastes from water and steam degreasing processes (except 1100)                                                                                                                          |
| 120301      | aqueous washing liquids                                                                                                                                                                 |
| 120302      | steam degreasing wastes                                                                                                                                                                 |
| 13          | Oil wastes (except edible oils, 0500 and 1200)                                                                                                                                          |
| 1301        | waste hydraulic oils and brake fluids                                                                                                                                                   |
| 130101      | hydraulic oils, containing PCBs or PCTs                                                                                                                                                 |
| 130102      | other chlorinated hydraulic oils (not emulsions)                                                                                                                                        |
| 130103      | non-chlorinated hydraulic oils (not emulsions)                                                                                                                                          |
| 130104      | chlorinated emulsions                                                                                                                                                                   |
| 130105      | non-chlorinated emulsions                                                                                                                                                               |

Table 17.6 Cont'd

| <i>Code</i> | <i>Description</i>                                                             |
|-------------|--------------------------------------------------------------------------------|
| 130106      | hydraulic oils containing only mineral oil                                     |
| 130107      | other hydraulic oils                                                           |
| 130108      | brake fluids                                                                   |
| 1302        | waste engine, gear and lubricating oils                                        |
| 130201      | chlorinated engine, gear and lubricating oils                                  |
| 130202      | non-chlorinated engine, gear and lubricating oils                              |
| 1303        | waste insulating and heat transmission oils and other liquids                  |
| 130301      | insulating or heat transmission oils and other liquids containing PCBs or PCTs |
| 130302      | other chlorinated insulating and heat transmission oils and other liquids      |
| 130303      | non-chlorinated insulating and heat transmission oils and other liquids        |
| 130304      | synthetic insulating and heat transmission oils and other liquids              |
| 130305      | mineral insulating and heat transmission oils                                  |
| 1304        | bilge oils                                                                     |
| 130401      | bilge oils from inland navigation                                              |
| 130402      | bilge oils from jetty sewers                                                   |
| 130403      | bilge oils from other navigation                                               |
| 1305        | oil/water separator contents                                                   |
| 130501      | oil/water separator solids                                                     |
| 130502      | oil/water separator sludges                                                    |
| 130503      | interceptor sludges                                                            |
| 130504      | desalter sludges or emulsions                                                  |
| 130505      | other emulsions                                                                |
| 1306        | oil waste not otherwise specified                                              |
| 130601      | oil waste not otherwise specified                                              |
| 14          | Wastes from organic substances employed as solvents (except 0700 and 0800)     |
| 1401        | wastes from metal degreasing and machinery maintenance                         |
| 140101      | chlorofluorocarbons                                                            |
| 140102      | other halogenated solvents and solvent mixes                                   |
| 140103      | other solvents and solvent mixes                                               |
| 140104      | aqueous solvent mixes containing halogens                                      |
| 140105      | aqueous solvent mixes free of halogens                                         |
| 140106      | sludges or solid wastes containing halogenated solvents                        |
| 140107      | sludges or solid wastes free of halogenated solvents                           |
| 1402        | wastes from textile cleaning and degreasing of natural products                |
| 140201      | halogenated solvents and solvent mixes                                         |
| 140202      | solvent mixes or organic liquids free of halogenated solvents                  |
| 140203      | sludges or solid wastes containing halogenated solvents                        |
| 140204      | sludges or solid wastes containing other solvents                              |
| 1403        | wastes from the electronic industry                                            |
| 140301      | chlorofluorocarbons                                                            |
| 140302      | other halogenated solvents                                                     |
| 140303      | solvents and solvent mixes free of halogenated solvents                        |
| 140304      | sludges or solid wastes containing halogenated solvents                        |
| 140305      | sludges or solid wastes containing other solvents                              |
| 1404        | wastes from coolants, foam/aerosol propellants                                 |
| 140401      | chlorofluorocarbons                                                            |
| 140402      | other halogenated solvents and solvent mixes                                   |
| 140403      | other solvents and solvent mixes                                               |
| 140404      | sludges or solid wastes containing halogenated solvents                        |
| 140405      | sludges or solid wastes containing other solvents                              |
| 1405        | wastes from solvent and coolant recovery (still bottoms)                       |
| 140501      | chlorofluorocarbons                                                            |
| 140502      | halogenated solvents and solvent mixes                                         |
| 140503      | other solvents and solvent mixes                                               |
| 140504      | sludges containing halogenated solvents                                        |
| 140505      | sludges containing other solvents                                              |

Table 17.6 Cont'd

| <i>Code</i> | <i>Description</i>                                                                                                                                      |
|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 16          | Wastes not otherwise specified in the catalogue                                                                                                         |
| 1602        | discarded equipment and shredder residues                                                                                                               |
| 160201      | transformers and capacitors containing PCBs or PCTs                                                                                                     |
| 1604        | waste explosives                                                                                                                                        |
| 160401      | waste ammunition                                                                                                                                        |
| 160402      | fireworks waste                                                                                                                                         |
| 160403      | other waste explosives                                                                                                                                  |
| 1606        | batteries and accumulators                                                                                                                              |
| 160601      | lead batteries                                                                                                                                          |
| 160602      | Ni-Cd batteries                                                                                                                                         |
| 160603      | mercury dry cells                                                                                                                                       |
| 160606      | electrolyte from batteries and accumulators                                                                                                             |
| 1607        | waste from transport and storage tank cleaning (except 0500 and 1200)                                                                                   |
| 160701      | waste from marine transport tank cleaning, containing chemicals                                                                                         |
| 160702      | waste from marine transport tank cleaning, containing oil                                                                                               |
| 160703      | waste from railway and road transport tank cleaning, containing oil                                                                                     |
| 160704      | waste from railway and road transport tank cleaning, containing chemicals                                                                               |
| 160705      | waste from storage tank cleaning, containing chemicals                                                                                                  |
| 160706      | waste from storage tank cleaning, containing oil                                                                                                        |
| 17          | Construction and demolition waste (including road construction)                                                                                         |
| 1706        | insulation materials                                                                                                                                    |
| 170601      | insulation materials containing asbestos                                                                                                                |
| 18          | Wastes from human or animal health care and/or related research (excluding kitchen and restaurant wastes which do not arise from immediate health care) |
| 1801        | waste from natal care, diagnosis, treatment or prevention of disease in humans                                                                          |
| 180103      | other wastes whose collection and disposal is subject to special requirements in view of the prevention of infection                                    |
| 1802        | waste from research, diagnosis, treatment or prevention of disease involving animals                                                                    |
| 180204      | other wastes whose collection and disposal is subject to special requirements in view of the prevention of infection by discarded chemicals             |
| 19          | Wastes from waste treatment facilities, off-site waste water treatment plants and the water industry                                                    |
| 1901        | wastes from incineration or pyrolysis of municipal and similar commercial, industrial and institutional wastes                                          |
| 190103      | fly ash                                                                                                                                                 |
| 190104      | boiler dust                                                                                                                                             |
| 190105      | filter cake from gas treatment                                                                                                                          |
| 190106      | aqueous liquid waste from gas treatment and other aqueous liquid wastes                                                                                 |
| 190107      | solid waste from gas treatment                                                                                                                          |
| 190110      | spent activated carbon from flue gas treatment                                                                                                          |
| 1902        | wastes from specific physico-chemical treatments of industrial wastes (e.g. dechromatation, decyanidation, neutralization)                              |
| 190201      | metal hydroxide sludges and other sludges from metal insolubilization treatment                                                                         |
| 1904        | vitrified wastes and wastes from vitrification                                                                                                          |
| 190402      | fly ash and other flue gas treatment wastes                                                                                                             |
| 190403      | fly ash and other flue gas treatment wastes non-vitrified solid phase                                                                                   |
| 1908        | wastes from waste water treatment plants not otherwise specified                                                                                        |
| 190803      | grease and oil mixture from oil/waste water separation                                                                                                  |
| 190806      | saturated or spent ion exchange resins                                                                                                                  |
| 190807      | solutions and sludges from regeneration of ion exchangers                                                                                               |
| 20          | Municipal wastes and similar commercial, industrial and institutional wastes including separately collected fractions                                   |
| 2001        | separately collected fractions                                                                                                                          |
| 200112      | paint, inks, adhesives and resins                                                                                                                       |
| 200113      | solvents                                                                                                                                                |
| 200117      | photo chemicals                                                                                                                                         |
| 200119      | pesticides                                                                                                                                              |
| 200121      | fluorescent tubes and other mercury containing waste                                                                                                    |

**Table 17.7 Hazard properties of Special Waste (see Table 17.6)**

| <i>Reference</i> | <i>Description</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| H1               | Explosive: substances and preparations which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| H2               | Oxidizing: substances and preparations which exhibit highly exothermic reactions when in contact with other substances, particularly flammable substances                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| H3-A             | Highly flammable:<br>liquid substances and preparations having a flash point below 21°C (including extremely flammable liquids), or<br>substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any application of energy, or<br>solid substances and preparations which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or<br>gaseous substances and preparations which are flammable in air at normal pressure, or<br>substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities |
| H3-B             | Flammable:<br>liquid substances and preparations having a flash point equal to or greater than 21 °C and less than or equal to 55 °C                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| H4               | Irritant: non-corrosive substances and preparations which, through immediate, prolonged or repeated contact with the skin or mucous membrane, can cause inflammation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| H5               | Harmful: substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may involve limited health risks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| H6               | Toxic: substances and preparations (including very toxic substances and preparations) which, if they are inhaled or ingested or if they penetrate the skin, may involve serious, acute or chronic health risks and even death                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| H7               | Carcinogenic substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce cancer or increase its incidence                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| H8               | Corrosive: substances and preparations which may destroy living tissue on contact                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| H9               | Infectious: substances containing viable micro-organisms or their toxins which are known or reliably believed to cause disease in man or other living organisms                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| H10              | Teratogenic: substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce non-hereditary congenital malformations or increase their incidence                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| H11              | Mutagenic: substances and preparations which if they are inhaled or ingested or if they penetrate the skin, may induce hereditary genetic defects or increase their incidence                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| H12              | Substances and preparations which release toxic or very toxic gases in contact with water, air or an acid                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| H13              | Substances and preparations capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the characteristics listed above                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| H14              | Ecotoxic: substances and preparations which present or may present immediate or delayed risks for one or more sectors of the environment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

Checking up on disposal.

Report any suspicions to the Environment Agency. Change carrier/contractor.

## Environmental Impact Assessment

An Environmental Impact Assessment is a technique by which information regarding the environmental effect of a project is collected, assessed and considered when reaching a decision on whether it should proceed. The assessment:

- provides a framework within which environmental considerations interact with design;
- can identify ways in which a project may be modified to minimize potential adverse environmental effects; and
- can assist in satisfying public interest that every possible impact has been considered.

|                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Section A – Description of waste</b>                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| 1. Please describe the waste being transferred:<br>2. How is the waste contained?<br>Loose <input type="checkbox"/> Sacks <input type="checkbox"/> Skip <input type="checkbox"/> Drum <input type="checkbox"/> Other <input type="checkbox"/> → Please describe<br>3. What is the quantity of waste (number of sacks, weight, etc.): |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| <b>Section B – Current holder of the waste</b>                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| 1. Full name (BLOCK CAPITALS):<br>2. Name and address of company:<br>3. Which of the following are you? (Please tick one or more boxes)                                                                                                                                                                                              |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| <input type="checkbox"/> producer of the waste<br><input type="checkbox"/> holder of waste disposal or waste management licence<br><br>Licence number:<br><br>Issued by:                                                                                                                                                             | <input type="checkbox"/> importer of the waste<br><input type="checkbox"/> exempt from requirement to have a waste disposal or waste management licence<br><br>Give reason:                    | <input type="checkbox"/> waste collection authority<br><input type="checkbox"/> registered waste carrier<br><br>Registration number:<br><br>Issued by: | <input type="checkbox"/> waste disposal authority (Scotland only)<br><input type="checkbox"/> exempt from requirement to register<br><br>Give reason: |
| <b>Section C – Person collecting the waste</b>                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| 1. Full name (BLOCK CAPITALS):<br>2. Name and address of company:<br>3. Which of the following are you? (Please tick one or more boxes)                                                                                                                                                                                              |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| <input type="checkbox"/> waste collection authority<br><input type="checkbox"/> holder of waste disposal or waste management licence<br><br>Licence number:<br><br>Issued by:                                                                                                                                                        | <input type="checkbox"/> waste disposal authority (Scotland only)<br><input type="checkbox"/> exempt from requirement to have a waste disposal or waste management licence<br><br>Give reason: | <input type="checkbox"/> exporter<br><input type="checkbox"/> registered waste carrier<br><br>Registration number:<br><br>Issued by:                   | <input type="checkbox"/> exempt from requirement to register<br><br>Give reason:                                                                      |
| <b>Section D</b>                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                       |
| 1. Address of place of transfer/collection point:<br><br>2. Date of transfer:<br>3. Time(s) of transfer (for multiple consignments, give 'between' dates):                                                                                                                                                                           | 4. Name and address of broker who arranged this waste transfer (if applicable):<br><br>5. Signed:<br>Full name:<br>Representing:<br><br>Signed:<br>Full name:<br>Representing:                 |                                                                                                                                                        |                                                                                                                                                       |

**Figure 17.2** *Controlled Waste Transfer Note to comply with Duty of Care*

An assessment normally includes a description of the proposed development, its location, design and scale. Data are included to enable the main effects which the development is likely to have to be assessed. There is then a description of the likely significant effects, either directly or indirectly, upon the environment. This will cover its impact upon:

water as per Tables 16.12–14 and 17.8;  
 land as per Table 17.8;  
 people;  
 air;  
 climate;  
 landscape, including visual impact;  
 material assets;  
 cultural heritage.

**Table 17.8 Considerations for impact upon water and land**

|       |                                                                                                                                                                                                                                                                                                                            |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Water | Flora and fauna, e.g. fisheries and shell beds                                                                                                                                                                                                                                                                             |
|       | Amenity, e.g. loss of recreation facilities                                                                                                                                                                                                                                                                                |
|       | Loss of potable water supplies (rivers, reservoirs, aquifers)                                                                                                                                                                                                                                                              |
|       | Agricultural water supplies, for irrigation and animal feedstock                                                                                                                                                                                                                                                           |
|       | Riverbanks, soils, sediments                                                                                                                                                                                                                                                                                               |
|       | Direct interaction of the substance, followed by slow release into the water may give long-term problems                                                                                                                                                                                                                   |
| Land  | The substance may simply collect in hollows and be gradually dispersed back into the main flow of water to give medium-term problems                                                                                                                                                                                       |
|       | Danger to crops, flora and vegetation. Action may range from disposal of crops to merely monitoring the contamination. The substance may also be washed off the crops or be biodegraded, although such processes are slower on land than in water. Deposition, followed by run-off to water sources or via soil permeation |
|       | Deposition followed by biodegradation, or persistence.                                                                                                                                                                                                                                                                     |

The consequential effects of transportation of materials to, and products and wastes from, the development are considered. For each significant potential impact identified, a description is required of the measures envisaged to mitigate the effects.

## Control of atmospheric emissions

Solvents such as 1,1,1-trichloroethane (methyl chloroform), carbon tetrachloride and CFC 113 are well known as ozone-depleting chemicals. They are commonly used as cleaning agents in a number of industries including engineering, electronics and dry cleaning. Companies using these solvents need to consider the impact of phasing them out in accordance with the decisions of the Montreal Protocol (e.g. see EC Decision 88/540/EEC and Regulation 3093/94) and seek alternative cleaning processes as costs are likely to rise as the substances will become increasingly difficult to obtain.

Small solid particles, present in dust and grit emissions, have very low settling velocities (Table 4.4) The collection efficiencies of simple cyclones are therefore, as shown in Figure 17.3, relatively low. Fabric filters, electrostatic precipitators or wet scrubbers may be required to remove particles <5 µm in size with an acceptable efficiency. Therefore the cost of pollution control inevitably increases when dealing with particle size distributions skewed towards the lower end.

The complexity of equipment required to arrest mists and sprays also increases with a reduction

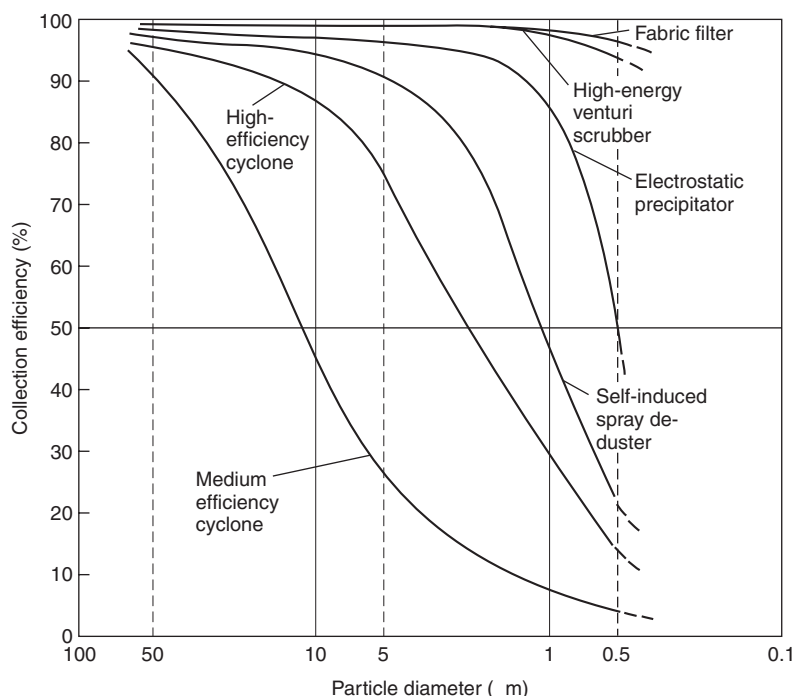


Figure 17.3 Particle arrestment efficiencies for different equipment

in droplet diameter. The range of droplet diameters associated with various processes, and the types of equipment used for their separation, are exemplified in Figure 17.4.

Processes for the control of atmospheric emissions are summarized in Table 17.9. Some of these involve the types of chemical engineering operations referred to in Chapter 7; the added complications are:

- the inlet pollutant concentrations may be quite low;
- the total stream flowrates may be large;
- the target outlet concentrations are probably subject to stringent regulation to very low levels.

As with pollution control equipment generally, a high degree of reliability is required.

## Liquid effluent treatment operations

Any of the variety of chemical engineering operations or unit processes listed in Table 17.10 may be used to treat aqueous effluents. Oxidation includes both chemical and biological processes; the latter include trickling filters or an activated sludge bed.

Process operation and the storage and handling of effluents and chemicals involve potential chemical and biological hazards (Chapter 5). Safeguards of the type outlined in Chapters 12 and 13 are essential, particularly since the activities are often on a site's periphery and have low manning levels.

EC policy is that waste oils from use as lubricants should be recycled or used as fuel as far as possible. Some EC countries have a more regulated organizational framework for collection and



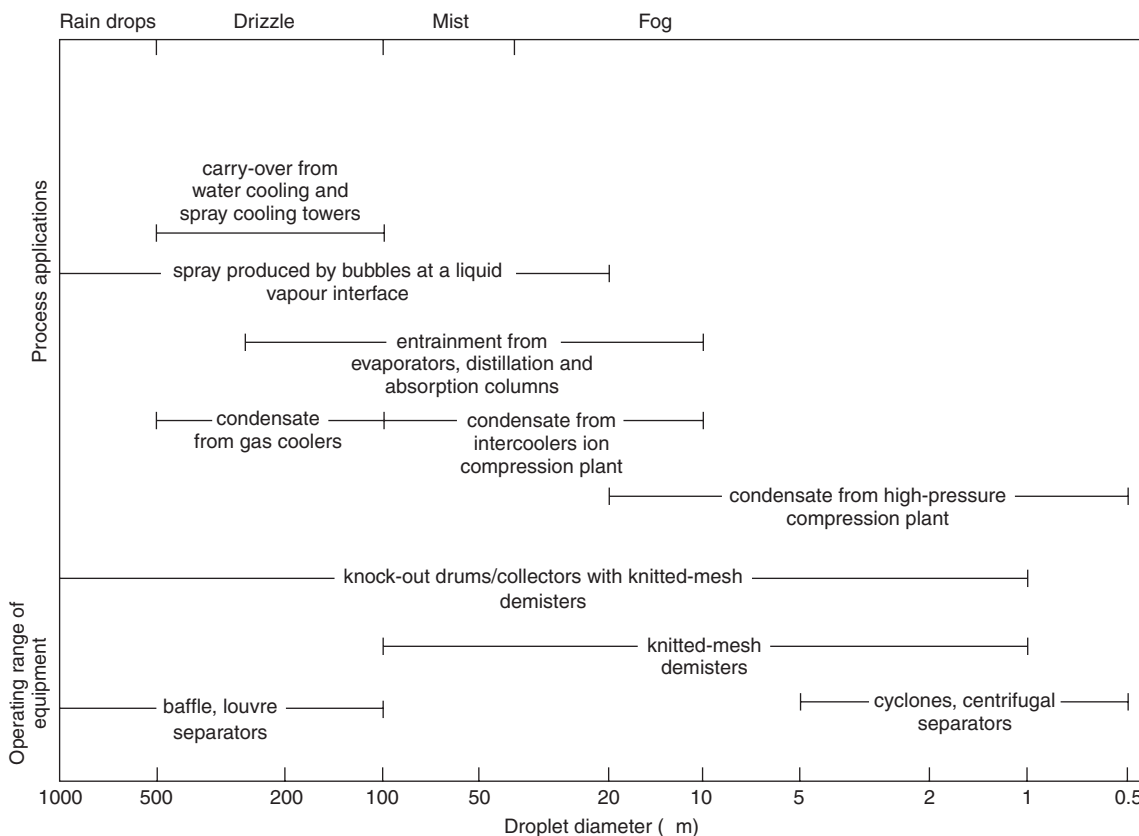


Figure 17.4 Mists and sprays; applications of separators

recycling of used oil. Used oil can be drained from machinery during routine servicing and should be stored in a central store using suitable leak-proof containers. Different types of oil should be stored separately. Used oils must not be disposed of into soakaways, watercourses, drains and sewers. The requirement of 'no visible oil' is often specified for releases to water, usually taken to mean no more than 20 ppm depending on droplet size. Used oils should only be disposed of to registered waste oil carriers. Alternatively waste oil can be burnt for heating provided that approval is given by the local authority Environmental Health Department for the installation of the burner.

The disposal of waste oils is largely governed in the UK by the EPA 90. Waste oils are a 'Special Waste' covered by Special Waste Regulations. Establishments handling more than 500 litres per annum have a duty to maintain records. There are also requirements for record keeping where waste oils contain toxic impurities and so become 'Special Waste'.

PCBs and PCTs are particularly troublesome liquids because of their toxicity and persistence in the environment. They are defined as polychlorinated biphenyls, polychlorinated terphenyls, monomethyl-dibromo-diphenyl methane, monomethyl-dichloro-diphenyl methane or monomethyl-tetrachlorodiphenyl methane. With low electrical conductivity and heat resistance they found wide use as dielectric fluids and were formerly used as hydraulic fluids. PCBs have not been made in the UK since 1977 and whilst most new uses for the substance are banned in most countries, around two-thirds of the 1.5 million tonnes manufactured in Europe and the US prior to 1985 still remain in equipment such as transformers. PCTs have been used in the past in a restricted range of specialist industrial applications.

**Table 17.9 Treatment methods for gaseous waste**

| <i>General methods</i>      | <i>Alternatives</i>                                                                                                                                                                                             |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Centrifugal techniques      | Centrifuge<br>Cyclone                                                                                                                                                                                           |
| Coalescence                 |                                                                                                                                                                                                                 |
| Condensation                |                                                                                                                                                                                                                 |
| Destruction                 | Chemical reaction<br>Incineration                                                                                                                                                                               |
| Direct recycle              |                                                                                                                                                                                                                 |
| Dispersion                  |                                                                                                                                                                                                                 |
| Electrostatic precipitation |                                                                                                                                                                                                                 |
| Filtration                  | Needle bonded fabric<br>Reverse jet<br>Reverse pressure<br>Shaker type                                                                                                                                          |
| Gravity settlement          |                                                                                                                                                                                                                 |
| Total enclosure             |                                                                                                                                                                                                                 |
| Wet scrubbing               | Absorption tower<br>Fluidized bed scrubber<br>Impingement scrubber<br>Irrigated target scrubber<br>Pressure spray scrubber<br>Rotary scrubber<br>Self-induced spray scrubber<br>Spray tower<br>Venturi scrubber |

**Waste gas treatment system**

| <i>Dry methods</i>          | <i>Pollutant</i> | <i>Wet methods</i>                                                                                             |
|-----------------------------|------------------|----------------------------------------------------------------------------------------------------------------|
| Absorption                  | <b>Gas</b>       | Wet scrubbing                                                                                                  |
| Destruction                 |                  |                                                                                                                |
| Direct recycling            |                  |                                                                                                                |
| Dispersion                  |                  |                                                                                                                |
| Total enclosure             |                  |                                                                                                                |
| Destruction                 | <b>Liquid</b>    | Centrifugal techniques<br>Coalescence<br>Destruction<br>Gravity settlement<br>Total enclosure<br>Wet scrubbing |
| Centrifugal techniques      | <b>Solid</b>     | Electrostatic precipitation<br>Wet scrubbing                                                                   |
| Destruction                 |                  |                                                                                                                |
| Direct recycling            |                  |                                                                                                                |
| Electrostatic precipitation |                  |                                                                                                                |
| Filtration                  |                  |                                                                                                                |
| Gravity settlement          |                  |                                                                                                                |
| Total enclosure             |                  |                                                                                                                |

**Table 17.10 Treatment methods for liquid effluent**

| <i>Treatment method</i>                                                        | <i>Example</i>                   |
|--------------------------------------------------------------------------------|----------------------------------|
| <b>Chemical</b>                                                                |                                  |
| Cementation                                                                    | Copper recovery                  |
| Chlorination                                                                   | Cyanide oxidation                |
| Coagulation, <i>see</i> Flocculation                                           |                                  |
| Electrolytic processes                                                         | Metal recovery                   |
| Emulsion breaking                                                              | Soluble oil recovery             |
| Flocculation                                                                   | Sewage treatment                 |
| Hydrolysis                                                                     | Cellulose waste                  |
| Incineration                                                                   | Waste oils                       |
| Ion exchange                                                                   | Metal recovery                   |
| Leaching                                                                       | Metal-bearing sludges            |
| Neutralization                                                                 | Waste acid, waste alkali         |
| Oxidation                                                                      | Phenol removal                   |
| Ozonization                                                                    | Cyanide oxidation                |
| Precipitation                                                                  | Metals                           |
| Reduction                                                                      | Hexavalent chromium              |
| Thermal decomposition                                                          | Recycling hydrochloric acid      |
| <b>Physical</b>                                                                |                                  |
| Adsorption                                                                     | Removal of volatile organics     |
| Cooling                                                                        | Water reuse                      |
| Crystallization                                                                | Recovery of inorganic salts      |
| Dewatering, <i>see</i> Filtration                                              |                                  |
| Dialysis                                                                       | Desalination                     |
| Distillation                                                                   | Solvent recovery                 |
| Drying                                                                         | Pig manure                       |
| Electrodialysis                                                                | Desalination                     |
| Evaporation                                                                    | Sulphuric acid recovery          |
| Filtration                                                                     | Sewage sludge                    |
| Flotation                                                                      | Dairy wastes                     |
| Foam fractionation                                                             | Metal separation                 |
| Fractionation, <i>see</i> Distillation                                         |                                  |
| Freezing                                                                       | Desalination                     |
| Heating                                                                        | Demulsification                  |
| Phase separation                                                               | Oily wastes, hydrocarbons        |
| Reverse osmosis                                                                | Desalination                     |
| Screening                                                                      | Sewage                           |
| Sedimentation                                                                  | Suspended solids removal         |
| Solvent extraction                                                             | Metal recovery                   |
| Stripping                                                                      | Ammonia removal, solvent removal |
| Ultrafiltration, <i>see</i> Dialysis, Reverse osmosis                          |                                  |
| <b>Biological</b>                                                              |                                  |
| Activated sludge                                                               | Sewage                           |
| Anaerobic digestion                                                            | Food wastes                      |
| Chemical production                                                            | Ethanol                          |
| Disinfection                                                                   | Sewage plant effluent            |
| High-rate filtration                                                           | Phenol removal                   |
| Oxidation, <i>see</i> Activated sludge, High-rate filtration, Trickling filter |                                  |
| Reduction, <i>see</i> Anaerobic digestion                                      |                                  |
| Single-cell protein production                                                 | Organic waste                    |
| Trickling filter                                                               | Sewage                           |

Under the requirements of the Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) (England and Wales) Regulations, SI 2000/1043, equipment containing PCBs is now required to be: identified, registered with the Environment Agency, labelled so that the PCB presence can be identified, and decontaminated without endangering health and safety to reduce the level of PCBs in equipment to less than 50 ppm (less than 0.005% in weight). It was, however, regarded as acceptable to achieve a level between 50 and 500 ppm and to dispose of equipment by 31 December 2000 unless the exemptions set out under the Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) Regulations, apply.

## **Control of solid waste**

The overall stages in handling waste are summarized in Figure 16.2. The treatment methods applicable to it are listed in Table 17.11.

The range of precautions required during handling, transfer, and disposal, e.g. by landfill, depend upon the risk including the nature and degree of contamination and the work to be undertaken.

It will, however, encompass personal protective equipment: a high standard of personal hygiene; enclosure, possibly pressurization and regular cleaning of vehicle cabs; vehicle washing facilities; site security, and control of designated dirty areas. Air monitoring and medical surveillance may be required.

## **Monitoring and auditing**

### ***Auditing***

The basic database for the control of environmental pollution is a pollution inventory, viz. a tabulation of emissions, discharges and wastes from the factory or activity covering all operating phases. This includes:

- atmospheric emissions; continuous, occasional and fugitive emissions during normal operation, start-up, shutdown, etc.;
- aqueous discharges; to sewers, direct to controlled waters, etc.;
- solid wastes; by type, origins, routes;
- noise; by reference to environmental noise surveys with identification of special features, tonal characteristics and intermittency;
- transport; normal plus any hazardous cargoes.

An environmental audit is a systematic, documented, periodic and objective evaluation of how well environmental organization, management and equipment are performing. The aim is to help safeguard the environment by:

- assessing compliance with company policies, including compliance with all regulatory requirements; and
- facilitating management control of environmental practices.

**Table 17.11 Treatment methods for solid waste**

| <i>Treatment method</i>  | <i>Examples/comments</i>                                             |
|--------------------------|----------------------------------------------------------------------|
| <b>Chemical</b>          |                                                                      |
| Calcination              | Gypsum                                                               |
| Chlorination             | Tin removal                                                          |
| Cooking                  | Inedible offal                                                       |
| Froth flotation          | Coal recovery                                                        |
|                          | Glass                                                                |
| Hydrolysis               | Household refuse                                                     |
|                          | Vegetable waste                                                      |
| Incineration             | Household refuse, rubber tyres                                       |
| Leaching                 | Gives an aqueous solution for treatment as liquid waste (Table 17.4) |
| Oxidation                | Weathering                                                           |
| Pyrolysis                | Household refuse                                                     |
|                          | Polystyrene                                                          |
| Sintering                | Colliery spoil                                                       |
|                          | Millscale                                                            |
| <b>Physical</b>          |                                                                      |
| Adhesion                 | Household refuse                                                     |
| Agglomeration            | Pulverized fuel ash                                                  |
| Ballistic separation     | Household refuse                                                     |
| Baling                   | Cans, paper, cardboard                                               |
| Centrifugation           | Animal oil separation                                                |
|                          | De-oiling swarf                                                      |
| Classification (air)     | Household refuse                                                     |
| Classification (wet)     | Plastic                                                              |
| Comminution              | Mining wastes                                                        |
|                          | Motor vehicles                                                       |
| Compaction               | Household refuse                                                     |
| Dewatering               | Sewage sludge                                                        |
| Dissolution              | Forms a liquid waste for treatment as in Table 17.4                  |
| Drying                   | Filter cake                                                          |
| Electrostatic separation | Household refuse                                                     |
| Foaming                  | Slag                                                                 |
| Freezing                 | Meat products                                                        |
| Granulation              | Slag                                                                 |
| Impalement               | Household refuse                                                     |
| Jigging                  | Household refuse                                                     |
| Magnetic treatment       | Iron removal from slag                                               |
|                          | Household refuse                                                     |
| Melting                  | Selective non-ferrous metal recovery                                 |
| Pelletization            | Iron and steel fines                                                 |
| Pulverization            | Household refuse                                                     |
|                          | Swarf                                                                |
| Quenching                | Incinerator residues                                                 |
| Screening                | Clinker                                                              |
| Settlement               | China clay wastes                                                    |
| Shape separation         | Household refuse                                                     |
| Sliding separation       | Household refuse, agricultural wastes                                |
| <b>Biological</b>        |                                                                      |
| Anaerobic digestion      | Farm waste                                                           |
| Bacterial leaching       | Low-grade copper ore                                                 |
| Composting               | Household refuse                                                     |
| Degradation              | Plastic                                                              |
| Fermentation             | Requires solution or dilute slurry, see Table 17.4                   |

Audits may differ. Some concentrate on particular facets, e.g. waste minimization, energy conservation. A management audit will probably cover organizational structures and relationships, communications, procedures acceptance and implementation, training and quality assurance. A technical audit will consider the performance of plant and equipment, monitoring and inspection programmes. Items for inclusion in auditing are listed in Table 17.12.

**Table 17.12 Some items in a typical environmental pollution audit**

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|                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Checks on environmental policy, organization and responsibilities, legislation, training records, emergency plans, performance targets, means of investigating incidents and written work instructions.                                                                                                                                                                  |
| Listing gaseous emissions, concentrations, smoke characteristics; prevailing winds and exposed zones; toxicity or nuisance potential; effects of synergism or poor atmospheric dispersing conditions. Consent limits. Compliance record keeping. Querying the adequacy of chimneys and stacks, scrubbers and particulates collection equipment (e.g. filters, cyclones). |
| Listing effluents, their analyses and discharge from processes. Querying flammability, corrosivity, toxicity, miscibility, reactivity. Checking the reliability of treatment and analysis. Consent limits. Compliance record keeping.                                                                                                                                    |
| Listing of 'solid' wastes, quantities, analyses and physical form (e.g. solid, slurry, suspension, sludge); 'toxicity' and flammability. Checking the reliability and legality of waste disposal options, including any transportation offsite. Record keeping.                                                                                                          |
| Bunding of storage areas, segregation of waste storage areas, security of landfill sites, etc.                                                                                                                                                                                                                                                                           |
| Soil contamination.                                                                                                                                                                                                                                                                                                                                                      |
| Monitoring (preferably continuous). Record keeping (on- and off-site).                                                                                                                                                                                                                                                                                                   |
| Checking for land contamination, e.g. analysis of soil samples. Record keeping.                                                                                                                                                                                                                                                                                          |
| Checks on waste removal. (Whilst a producer is under no obligation to audit his waste's final destination, such a visit is a prudent means of demonstrating the steps taken to prevent subsequent illegal treatment of the waste.)                                                                                                                                       |
| Checking noise levels (on- and off-site).                                                                                                                                                                                                                                                                                                                                |

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Specific attention is given to auditing for compliance with legislation, including the requirements of IPC, BATNEEC and BPEO.

## ***Monitoring***

Monitoring of emissions, discharges and disposals is a prerequisite of control. Depending upon the waste stream, sampling and analysis may be continuous or periodic. Measurement methods for physico-chemical properties and chemical analysis of waste streams are very diverse. The data obtained are used both for monitoring to ensure adequate control and compliance with legislation, and for process plant design and operation – including recycling and recovery. A selective list of methods for physico-chemical properties is given in Table 17.13 and for chemical analysis in Table 17.14.

All the parameters on which various consents (or permissions to dispose of, waste streams) are based must be reliably measured and recorded. This is easier to achieve with gaseous emissions (Chapter 10) and liquid effluents than with heterogeneous solid wastes. Systematic analysis of solid wastes will cover as a minimum the information in Table 17.15.

The gold standard for environment management systems is BS EN ISO 14001 as summarized by Table 17.16.

**Table 17.13 Methods for measurement of physico-chemical properties**  
(R = routine test)

**Gaseous wastes**

| <i>Property</i>                                                | <i>For consideration</i>                                                                | <i>Methods</i>                                                                            |
|----------------------------------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| <b>Gases generally</b>                                         |                                                                                         |                                                                                           |
| Calorific value                                                | Incineration with/without heat recovery                                                 | Calculation from published data<br>Calorimeters                                           |
| Concentration of gaseous (R) pollutant                         | Disposal constraints<br>Design of treatment/disposal/recovery plant                     | Chemical analysis (q.v.)<br>Chromatography                                                |
| Density                                                        | Dispersion<br>Design of disposal/treatment plant                                        | Chancel flask, or effusiometer                                                            |
| Dewpoint                                                       | Design of treatment/disposal/recovery plant<br>Condensation                             | Tabulated<br>Hygrometer ASTM method                                                       |
| Flammable limits                                               | Fire and explosion hazard<br>Control of combustion                                      | Tabulated                                                                                 |
| Flammability                                                   | Fire and explosion hazard<br>Control of combustion                                      | see Calorific value and<br>Flammable limits<br>ASTM methods                               |
| Ignition temperature                                           | Fire and explosion hazard<br>Control of combustion                                      | Adiabatic compression<br>Concentric tube<br>Tabulated                                     |
| Moisture content                                               | see Dewpoint<br>Potential nuisance<br>Disposal<br>Necessity for treatment               | Subjective testing<br>ASTM methods<br>Proprietary meters                                  |
| Pressure                                                       | Design of treatment/disposal/recovery plant                                             | Gauges<br>Transducer<br>Manometer                                                         |
| Solubility of pollutant (R)                                    | Design of separation/treatment plant                                                    | Wide range<br>ASTM methods<br>Tabulated                                                   |
| Temperature (R)                                                | Corrosion resistance<br>Design of treatment/disposal plant<br>Materials of construction | Thermometer<br>Thermocouple<br>Resistance treatment<br>Pyrometer<br>ASTM methods          |
| Velocity (R)                                                   | Design of disposal/treatment plant                                                      | Pitot tube<br>Anemometer<br>Orifice plate, etc.<br>Rotameter<br>Gas meters<br>ASTM method |
| Viscosity                                                      | Design of disposal/treatment plant                                                      | Calculated or tabulated                                                                   |
| <b>Liquids suspended in gases<br/>(see also Liquid wastes)</b> |                                                                                         |                                                                                           |
| Concentration of liquid pollutants (R)                         | Design of treatment/recovery plant<br>Legislation                                       | Sampling and analysis                                                                     |
| Density of liquid                                              | Design of treatment/recovery plant                                                      | ASTM methods<br>Pyknometer<br>Hydrometer<br>Relative density balance<br>Tabulated         |

Table 17.13 Cont'd

| <i>Property</i>                                                    | <i>For consideration</i>                                     | <i>Methods</i>                                                                |
|--------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------------|
| Electrical properties                                              | Electrostatic precipitation                                  | Direct testing                                                                |
| Flammability and related properties                                | Fire/explosion hazard                                        | see Non-aqueous liquids                                                       |
| Droplet size distribution                                          | Incineration                                                 |                                                                               |
|                                                                    | Design of treatment/recovery plant                           | Numerous including:<br>Holography                                             |
|                                                                    | Environmental impact                                         | Light scatter<br>ASTM methods                                                 |
| pH of liquid                                                       | Corrosion resistance                                         | Indicators                                                                    |
|                                                                    | Environmental impact                                         | Test meter<br>pH meter                                                        |
| Surface tension of liquid                                          | Coalescence for removal                                      | Tabulated                                                                     |
|                                                                    | Design of treatment/recovery plant                           | ASTM methods                                                                  |
| Viscosity of liquid                                                | Design of treatment plant for removal                        | ASTM methods<br>Viscometer<br>Tabulated                                       |
| <b>Solids suspended in gases</b><br><b>(see also Solid wastes)</b> |                                                              |                                                                               |
| Concentration of solid in gas (R)                                  | Design of treatment or recovery plant                        | Sampling                                                                      |
|                                                                    | Legislation                                                  | Density meter                                                                 |
| Density (bulk)                                                     | Design of treatment or recovery plant and handling equipment | Direct measurement<br>ASTM methods                                            |
| Density (particle)                                                 | Design of separation equipment                               | Displacement<br>Pyknometer<br>Tabulated<br>ASTM methods                       |
| Electrical properties                                              | Electrostatic precipitation                                  | Direct testing                                                                |
| Flammability and related properties                                | Fire and explosion hazard                                    | ASTM methods                                                                  |
| Hygroscopicity                                                     | Dust explosion hazard                                        | see Solid wastes                                                              |
|                                                                    | Collection and removal of solid                              | Direct measurement with exposure<br>ASTM method                               |
| Particle geometry                                                  | Design of separation equipment                               | Observation<br>ASTM method                                                    |
| Particle size distribution (R)                                     | Toxic hazard                                                 |                                                                               |
|                                                                    | Design of separation equipment                               |                                                                               |
|                                                                    | Toxic hazard                                                 |                                                                               |
|                                                                    | Environmental impact                                         | Wide range including:<br>Microscopy<br>Holography<br>Light scatter<br>Sieving |
| Solubility (R)                                                     | Solubility for removal by dissolution                        | Wide range<br>Tabulated                                                       |
| Wettability                                                        | Suitability for removal by scrubbing                         | Experimentation<br>ASTM method                                                |

**Liquid wastes****Aqueous liquids**

|                                    |                            |           |
|------------------------------------|----------------------------|-----------|
| Ash                                | Incineration               | Ignition  |
| BOD (Biological Oxygen Demand) (R) | Type of treatment required | Dilution  |
|                                    | Legislation and controls   | Manometry |



**Table 17.13 Cont'd**

| <i>Property</i>              | <i>For consideration</i>                                                                           | <i>Methods</i>                                                                                     |
|------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| COD (Chemical Oxygen Demand) | Legislation and controls                                                                           | Oxidation by dichromate                                                                            |
| Colour (R)                   | Legislation and controls                                                                           | Visual comparison<br>ASTM methods                                                                  |
| Density (bulk)               | Extent of contamination<br>Design of treatment or recovery plant                                   | Hydrometer<br>Pyknometer<br>Relative density balance<br>General                                    |
| Density (liquid droplet)     | Emulsion breaking<br>Stability<br>Design of treatment or recovery plant                            | Hydrometer<br>Pyknometer<br>Relative density balance<br>Tabulation                                 |
| Density (solid particle)     | Design of treatment or recovery plant (gravity settling)                                           | ASTM methods<br>Displacement<br>Pyknometer<br>Tabulated                                            |
| Flowrate (R)                 | Design of treatment or recovery plant                                                              | ASTM methods<br>Wide range including:<br>Meters<br>Orifice plates<br>Pitot tubes<br>Venturi meters |
| Non-aqueous liquid content   | Design of treatment or recovery plant                                                              | Breaking emulsion<br>Solvent extraction<br>ASTM methods                                            |
| Odour                        | Legislation and controls<br>Nuisance                                                               | Subjective, empirical                                                                              |
| Particle size distribution   | Design of treatment or recovery plant                                                              | see Suspensions in gases                                                                           |
| Permanganate value           | Legislation and controls                                                                           | Oxidation with permanganate                                                                        |
| pH (R)                       | Corrosion<br>Legislation and controls                                                              | Test paper<br>pH meter<br>Titration                                                                |
| Surface tension              | Foaming<br>Design of treatment/recovery plant                                                      | ASTM methods<br>Tabulated<br>Capillary height<br>Bubble pressure<br>Drop                           |
| Suspended solids (R)         | Design of treatment/recovery plant<br>Legislation and controls                                     | Filtration<br>Centrifuge<br>ASTM methods                                                           |
| Taste                        | Contamination of potable water                                                                     | Subjective and/or empirical<br>ASTM methods                                                        |
| Temperature (R)              | Legislation and controls                                                                           | Thermocouple<br>Thermometer<br>Resistance thermometers<br>ASTM methods                             |
| Total dissolved solids (R)   | Legislation and controls<br>Design of treatment/recovery plant                                     | Evaporation<br>Electrical conduction<br>ASTM methods                                               |
| Turbidity                    | Legislation and controls                                                                           | ASTM method<br>Turbidity meter ( <i>see also</i> Suspended solids)                                 |
| Vapour pressure              | Fire and explosion hazard<br>Design of treatment/recovery plant<br>Vapour-release (toxic, odorous) | Viscometer<br>ASTM methods<br>Tabulated                                                            |

Table 17.13 Cont'd

| <i>Property</i>            | <i>For consideration</i>                                                                                     | <i>Methods</i>                                                                                                                                            |
|----------------------------|--------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Non-aqueous liquids</b> |                                                                                                              |                                                                                                                                                           |
| Ash                        | Incineration with/without heat recovery                                                                      | Ignition                                                                                                                                                  |
| BOD                        | Design of treatment plant<br>Legislation and controls                                                        | Dilution<br>Manometry<br>Probe                                                                                                                            |
| Boiling point (R)          | Design of separation equipment<br>Fire and explosion hazard<br>Handling and storage                          | Wide range including:<br>Conventional boiling point<br>Ebulliometer<br>Ramsay and Young<br>Tabulated<br>(see also Vapour pressure and Distillation range) |
| Calorific value            | see Heat of combustion                                                                                       | —                                                                                                                                                         |
| COD                        | Design of treatment plant<br>Legislation and controls                                                        | Oxidation by acid dichromate                                                                                                                              |
| Density (bulk)             | Design of treatment/recovery plant, e.g. gravity settling                                                    | Hydrometer<br>Pyknometer<br>Relative density balance<br>ASTM methods                                                                                      |
| Density (particle)         | Design of treatment/recovery plant                                                                           | Displacement<br>Pyknometer<br>Tabulated<br>ASTM methods                                                                                                   |
| Distillation range         | Design of recovery plant<br>Incineration                                                                     | Distillation<br>ASTM methods                                                                                                                              |
| Flammable limits           | Fire and explosion hazard<br>Handling and storage                                                            |                                                                                                                                                           |
| Flash point (R)            | Fire and explosion hazard<br>Handling and storage                                                            | Abel<br>Cleveland<br>Pensky Martin<br>Equilibrium apparatus (various)<br>see Gases                                                                        |
| Flowrate (R)               | Design of treatment/recovery plant                                                                           |                                                                                                                                                           |
| Heat of combustion         | Incineration with/without heat recovery                                                                      | Bomb calorimeter<br>Tabulated                                                                                                                             |
| Interfacial tension        | Design of treatment/recovery plant                                                                           | see Surface tension<br>ASTM methods                                                                                                                       |
| Miscibility with water     | Design of treatment/recovery plant<br>Evaporation rate<br>Spillage control                                   | Wide range including:<br>Hill<br>Hertz<br>Tabulated                                                                                                       |
| Odour                      | Legislation and controls                                                                                     | Subjective, empirical<br>ASTM methods                                                                                                                     |
| Temperature (R)            | Design of treatment/recovery plant<br>Fire and explosion hazard<br>Handling and storage                      | Resistance thermometry<br>Thermocouple<br>Thermometer<br>ASTM methods                                                                                     |
| Vapour pressure (R)        | Design of treatment/recovery plant<br>Evaporation rate<br>Fire and explosion hazards<br>Handling and storage | Isoteriscope<br>Micro<br>Reid<br>Tabulated<br>see also Boiling point<br>ASTM methods                                                                      |
| Viscosity                  | Design of treatment/<br>disposal/recovery plant                                                              | Viscometer<br>ASTM methods<br>Tabulated                                                                                                                   |

**Table 17.13 Cont'd**

| <i>Property</i>            | <i>For consideration</i>                                                                                                                                            | <i>Methods</i>                                                                                |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Volatility                 | Fire and explosion hazard<br>Handling and storage<br>Vapour release                                                                                                 | see Distillation range and<br>Vapour pressure                                                 |
| <b>Solid wastes</b>        |                                                                                                                                                                     |                                                                                               |
| Angle of repose            | Handling and storage                                                                                                                                                | Direct measurement                                                                            |
| Ash                        | Disposal<br>Incineration                                                                                                                                            | ASTM methods<br>Radiation methods<br>see Loss on ignition<br>Bomb calorimeter<br>ASTM methods |
| Calorific value            | Incineration                                                                                                                                                        |                                                                                               |
| Combustibility (R)         | Fire hazard                                                                                                                                                         |                                                                                               |
| Compressibility            | Disposal                                                                                                                                                            | Arbitrary methods relating<br>changes in bulk density<br>ASTM methods                         |
| Density (actual)           | Design of treatment/disposal/<br>recovery plant                                                                                                                     | Pyknometer<br>Displacement<br>Tabulated<br>ASTM methods                                       |
| Density (bulk)             | Handling and storage<br>Disposal                                                                                                                                    | Direct measurement of weight<br>and volume<br>Bulk density/ash meter<br>ASTM methods          |
| Elasticity                 | Handling and storage<br>Disposal                                                                                                                                    | Tabulated<br>Experimentation                                                                  |
| Flowrate (R)               | Design of treatment/recovery<br>plant                                                                                                                               | Meters<br>Impact flow meter                                                                   |
| Hardness                   | Handling<br>Design of treatment/recovery<br>plant                                                                                                                   | Radiation<br>Tabulated<br>ASTM methods                                                        |
| Hygroscopicity             | Disposal                                                                                                                                                            | Experimentation                                                                               |
| Loss on ignition           | Handling and storage<br>Incineration                                                                                                                                | see Water absorption                                                                          |
| Mineralogy                 | Disposal                                                                                                                                                            | Ignition<br>ASTM methods                                                                      |
| Oil content                | Potential reuse<br>Disposal<br>Incineration                                                                                                                         | Examination                                                                                   |
| Particle size distribution | Fire and explosion hazard<br>Handling and storage<br>Disposal<br>Design of treatment/recovery<br>plant<br>Environmental impact<br>(atmosphere dispersion, settling) | Extraction with solvent                                                                       |
| pH                         | Corrosion<br>Design of treatment/recovery<br>plant                                                                                                                  | Wide range including:<br>Holography<br>Microscopy<br>Sieving<br>ASTM methods                  |
| Physical composition       | Design of treatment/recovery<br>plant<br>Handling<br>Disposal                                                                                                       | Test paper<br>pH meter<br>Titration                                                           |
| Porosity                   | Disposal                                                                                                                                                            | Examination and observation                                                                   |
|                            |                                                                                                                                                                     | Calculated from bulk density (q.v.)                                                           |

**Table 17.13 Cont'd**

| <i>Property</i>  | <i>For consideration</i>           | <i>Methods</i>                                     |
|------------------|------------------------------------|----------------------------------------------------|
| Solubility       | Design of treatment/recovery plant | Wide range including:<br>Campbell                  |
|                  | Environmental impact (leaching)    | Weyl                                               |
| Volatile matter  | Fire and explosion hazard          | Tabulated                                          |
|                  | Incineration                       | Heating                                            |
| Water content    | Handling and storage               | ASTM methods                                       |
|                  | Disposal                           | <i>see also</i> Distillation range                 |
|                  |                                    | Drying to constant weight                          |
|                  |                                    | BS and ASTM methods                                |
|                  |                                    | Range of methods including:                        |
|                  |                                    | Microwave attenuation                              |
|                  |                                    | Capacitance                                        |
|                  |                                    | Resistivity                                        |
|                  |                                    | Infra-red absorption                               |
|                  |                                    | Neutron moderation                                 |
| Water absorption | Disposal                           | Experimentation                                    |
|                  | Handling and storage               | ASTM methods                                       |
| Wettability      | Design of treatment/recovery plant | Angle of contact related to surface tension (q.v.) |

Sources of test methods: ASTM (American Society of Testing and Materials); IP (Institute of Petroleum); BS (British Standard).

**Table 17.14 Methods of chemical analysis**

| <i>Method</i>                           | <i>Application</i> |                       |                            |                          |              |               |              |
|-----------------------------------------|--------------------|-----------------------|----------------------------|--------------------------|--------------|---------------|--------------|
|                                         | <i>Metals</i>      | <i>Other elements</i> | <i>Inorganic chemicals</i> | <i>Organic chemicals</i> | <i>Phase</i> |               |              |
|                                         |                    |                       |                            |                          | <i>Gas</i>   | <i>Liquid</i> | <i>Solid</i> |
| Amperometry                             | +                  | +                     | (+)                        | +                        |              | +             |              |
| Atomic absorption spectrometry          | +                  |                       |                            |                          |              | +             | +            |
| Atomic emission spectrometry            | +                  | (+)                   | (+)                        |                          |              | +             |              |
| Atomic fluorescence spectrometry        | +                  | (+)                   | (+)                        |                          |              | +             |              |
| Conductometry                           | +                  | (+)                   | +                          |                          |              | +             |              |
| Coulometry                              | +                  | (+)                   | (+)                        |                          |              | +             |              |
| Electrogravimetry                       | (+)                |                       |                            |                          |              | +             |              |
| Electrophoresis                         |                    |                       |                            | +                        |              | +             | +            |
| Flame photometry                        | +                  |                       |                            |                          |              | +             | (+)          |
| Gas chromatography                      | (+)                |                       |                            | +                        | +            | +             | (+)          |
| Fluorimetry                             | (+)                |                       |                            | +                        |              | +             | +            |
| Helium plasma                           | +                  | +                     |                            |                          | +            | +             | +            |
| Infra-red spectrometry                  |                    |                       | (+)                        | +                        | +            | +             | +            |
| Isotope dilution                        | +                  | +                     |                            |                          | +            | +             | +            |
| Mass spectrometry                       |                    |                       |                            | +                        | +            | +             |              |
| Nuclear magnetic resonance spectrometry | (+)                | +                     | (+)                        | +                        |              | +             |              |
| Polarimetry                             |                    |                       |                            | +                        |              |               | +            |
| Polarography                            | +                  |                       | +                          | +                        |              | +             |              |
| Potentiometry                           | +                  |                       | +                          |                          |              | +             |              |
| Radioactivity                           | +                  | +                     |                            |                          | +            | +             | +            |
| Raman spectroscopy                      |                    |                       | +                          | +                        | +            | +             | +            |
| Spark (emission) spectrograph           |                    | +                     |                            |                          |              |               | +            |
| Specific ion electrode                  | +                  | +                     | +                          |                          | +            | +             | +            |
| Thin layer chromatography               |                    |                       |                            | +                        |              | +             | +            |
| Ultraviolet spectrometry                |                    |                       | (+)                        | +                        | +            | +             |              |
| Visible light spectrometry              |                    |                       | +                          |                          | +            | +             |              |
| X-ray diffraction spectrometry          |                    |                       | +                          | +                        |              |               | +            |
| X-ray fluorescence spectrometry         | +                  | +                     |                            |                          |              |               | +            |

**Table 17.15 Minimum analysis for solid waste sample**

|                      |                                                                                                                                                                                                                                                    |                                                                                     |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| For inorganic wastes | Reaction with water<br>Reaction with acids<br>Reaction with alkalis<br>Effect of heat<br>pH, total solids<br>Presence of sulphides, total cyanide, ammonium compounds<br>Concentration of metals, particularly Pb, Zn, Cd, Hg, Sn, As, Cu, Cr, Ni  | For mixtures of inorganic and organic wastes all these analyses should be completed |
| For organic wastes   | Calorific value<br>Flash point<br>Miscibility with water (or other wastes)<br>Viscosity at various temperatures<br>Halogen, sulphur, nitrogen content<br>Ash content<br>Analysis of ash<br>Organic content by BOD, COD, PV or total carbon methods |                                                                                     |

**Table 17.16 Elements of ISO 14001**

|       |                                                      |
|-------|------------------------------------------------------|
| 1     | Scope                                                |
| 2     | Normative references                                 |
| 3     | Definitions                                          |
| 4     | Environmental management system requirements         |
| 4.1   | General requirements                                 |
| 4.2   | Environmental policy                                 |
| 4.3   | Planning                                             |
| 4.3.1 | Environmental aspects                                |
| 4.3.2 | Legal and other requirements                         |
| 4.3.3 | Objectives and targets                               |
| 4.3.4 | Environmental management programmes                  |
| 4.4   | Implementation and operation                         |
| 4.4.1 | Structure and responsibility                         |
| 4.4.2 | Training, awareness and competence                   |
| 4.4.3 | Communication                                        |
| 4.4.4 | Environmental management system documentation        |
| 4.4.5 | Document control                                     |
| 4.4.6 | Operational control                                  |
| 4.4.7 | Emergency preparedness and response                  |
| 4.5   | Checking and corrective action                       |
| 4.5.1 | Monitoring and measurement                           |
| 4.5.2 | Non-conformance and corrective and preventive action |
| 4.5.3 | Records                                              |
| 4.5.4 | Environmental management system audit                |
| 4.6   | Management review                                    |

# Conversion tables and measurement data

## Frequently used atomic weights

| <i>Element</i> | <i>Symbol</i> | <i>Atomic weight</i> | <i>Element</i> | <i>Symbol</i> | <i>Atomic weight</i> |
|----------------|---------------|----------------------|----------------|---------------|----------------------|
| Aluminium      | Al            | 26.98                | Magnesium      | Mg            | 24.31                |
| Antimony       | Sb            | 121.75               | Manganese      | Mn            | 54.94                |
| Argon          | Ar            | 39.95                | Mercury        | Hg            | 200.59               |
| Arsenic        | As            | 74.92                | Molybdenum     | Mo            | 95.94                |
| Barium         | Ba            | 137.34               | Nickel         | Ni            | 58.71                |
| Beryllium      | Be            | 9.01                 | Nitrogen       | N             | 14.01                |
| Bismuth        | Bi            | 208.98               | Oxygen         | O             | 16.00                |
| Boron          | B             | 10.81                | Phosphorus     | P             | 30.97                |
| Bromine        | Br            | 79.90                | Platinum       | Pt            | 195.09               |
| Cadmium        | Cd            | 112.40               | Potassium      | K             | 39.10                |
| Calcium        | Ca            | 40.08                | Selenium       | Se            | 78.96                |
| Carbon         | C             | 12.01                | Silicon        | Si            | 28.09                |
| Chlorine       | Cl            | 35.45                | Silver         | Ag            | 107.87               |
| Chromium       | Cr            | 52.00                | Sodium         | Na            | 22.99                |
| Cobalt         | Co            | 58.93                | Strontium      | Sr            | 87.62                |
| Copper         | Cu            | 63.55                | Sulphur        | S             | 32.06                |
| Fluorine       | F             | 19.00                | Tantalum       | Ta            | 189.95               |
| Gold           | Au            | 196.97               | Tin            | Sn            | 118.69               |
| Helium         | He            | 4.00                 | Titanium       | Ti            | 47.90                |
| Hydrogen       | H             | 1.01                 | Tungsten       | W             | 183.85               |
| Iodine         | I             | 126.90               | Uranium        | U             | 238.03               |
| Iron           | Fe            | 55.85                | Vanadium       | V             | 50.94                |
| Lead           | Pb            | 207.19               | Zinc           | Zn            | 65.37                |
| Lithium        | Li            | 6.94                 | Zirconium      | Zr            | 91.22                |

**SI Units**

| <i>Quantity</i>                          | <i>Unit</i> | <i>Symbol</i> | <i>Equivalent</i>   |
|------------------------------------------|-------------|---------------|---------------------|
| <b>Base units</b>                        |             |               |                     |
| Length                                   | metre       | m             | —                   |
| Mass                                     | kilogramme  | kg            | —                   |
| Time                                     | second      | s             | —                   |
| Electric current                         | ampere      | A             | —                   |
| Temperature                              | kelvin      | K             | —                   |
| Luminous intensity                       | candela     | cd            | —                   |
| <b>Supplementary units</b>               |             |               |                     |
| Plane angle                              | radian      | rad           | —                   |
| Solid angle                              | steradian   | sr            | —                   |
| <b>Derived units</b>                     |             |               |                     |
| Frequency                                | hertz       | Hz            | s <sup>-1</sup>     |
| Force                                    | newton      | N             | kg m/s <sup>2</sup> |
| Work, energy, quantity of heat           | joule       | J             | Nm                  |
| Power                                    | watt        | W             | J/s                 |
| Electric charge, quantity of electricity | coulomb     | C             | As                  |
| Electric potential, electromotive force  | volt        | V             | W/A                 |
| Electric capacitance                     | farad       | F             | C/V                 |
| Electric resistance                      | ohm         | Ω             | V/A                 |
| Magnetic flux                            | weber       | Wb            | Vs                  |
| Magnetic flux density                    | tesla       | T             | Wb/m <sup>2</sup>   |
| Inductance                               | henry       | H             | Wb/A                |
| Luminous flux                            | lumen       | lm            | cd sr               |
| Illumination                             | lux         | lx            | lm/m <sup>2</sup>   |

**Other metric units**

| <i>Quantity</i>         | <i>Unit</i>       | <i>Symbol</i> | <i>Equivalent</i>                                 |
|-------------------------|-------------------|---------------|---------------------------------------------------|
| Length                  | angstrom          | Å             | 10 <sup>-10</sup> m                               |
|                         | micrometre        | μm            | 10 <sup>-6</sup> m                                |
| Area                    | are               | a             | 10 <sup>2</sup> m <sup>2</sup>                    |
| Volume                  | litre             | l             | 10 <sup>-3</sup> m <sup>3</sup>                   |
| Mass                    | tonne             | t             | 10 <sup>3</sup> kg                                |
| Force                   | dyne              | —             | 10 <sup>-5</sup> N                                |
| Pressure                | pascal            | Pa            | 1 N/m <sup>2</sup>                                |
|                         | bar               | bar           | 10 <sup>5</sup> N/m <sup>2</sup>                  |
| Energy                  | erg               | —             | 10 <sup>-7</sup> J                                |
| Viscosity (dynamic)     | centipoise        | cP            | 10 <sup>-3</sup> Ns/m <sup>2</sup><br>(= 1 mPa s) |
| Viscosity (kinetic)     | centistokes       | cSt           | 10 <sup>-6</sup> m <sup>2</sup> /s                |
| Electrical conductivity | siemens           | S             | 1 Ω <sup>-1</sup>                                 |
| Magnetic field strength | oersted           | —             | 10 <sup>3</sup> /4πA/m                            |
| Magnetomotive force     | gilbert           | —             | 10/4πA                                            |
| Magnetic flux density   | gauss             | —             | 10 <sup>-4</sup> T                                |
| Magnetic flux           | maxwell (or line) | —             | 10 <sup>-8</sup> Wb                               |
| Luminance               | nit               | nt            | 1 cd/m <sup>2</sup>                               |
|                         | Stilb             | —             | 10 <sup>4</sup> cd/m <sup>2</sup>                 |

**Multiples and sub-multiples of units**

| <i>Factor</i> | <i>Prefix</i> | <i>Symbol</i> |
|---------------|---------------|---------------|
| $10^{18}$     | exa           | E             |
| $10^{15}$     | peta          | P             |
| $10^{12}$     | tera          | T             |
| $10^9$        | giga          | G             |
| $10^6$        | mega          | M             |
| $10^3$        | kilo          | k             |
| $10^2$        | hecto         | h             |
| 10            | deca          | da            |
| $10^{-1}$     | deci          | d             |
| $10^{-2}$     | centi         | c             |
| $10^{-3}$     | milli         | m             |
| $10^{-6}$     | micro         |               |
| $10^{-9}$     | nano          | n             |
| $10^{-12}$    | pico          | p             |
| $10^{-15}$    | femto         | f             |
| $10^{-18}$    | atto          | a             |

**Temperature**

|   |                                        |
|---|----------------------------------------|
| C | $C + 273.15 = K$                       |
|   | $C \times (1.8) + 32 = F$              |
|   | $C \times (1.8) + 491.58 = R$          |
| F | $F + 459.48 = R$                       |
|   | $(F - 32) \times 5/9 = C$              |
|   | $(F - 32) \times 5/9 + 273.15 = K$     |
| K | $K - 273.15 = C$                       |
|   | $(K - 273.15) \times 1.8 + 32 = F$     |
| R | $R - 459.48 = F$                       |
|   | $R - 491.58 \times 5/9 = C$            |
|   | $(R - 491.58) \times 5/9 + 273.15 = K$ |

**Length**

|                        | <i>To obtain:</i> |           |           |                    |                     |                       |                        |
|------------------------|-------------------|-----------|-----------|--------------------|---------------------|-----------------------|------------------------|
|                        | <b>m</b>          | <b>cm</b> | <b>mm</b> | <b>m</b>           | <b>Å</b>            | <b>in</b>             | <b>ft</b>              |
| <i>Multiply no. of</i> |                   |           |           |                    |                     |                       |                        |
| <b>m by</b>            | 1                 | 100       | 1000      | $10^6$             | $10^{10}$           | 39.37                 | 3.28                   |
| <b>cm by</b>           | 0.01              | 1         | 10        | $10^4$             | $10^8$              | 0.394                 | 0.0328                 |
| <b>mm by</b>           | 0.001             | 0.1       | 1         | $10^3$             | $10^7$              | 0.0394                | 0.00328                |
| <i>by</i>              | $10^{-6}$         | $10^{-4}$ | $10^{-3}$ | 1                  | $10^4$              | $3.94 \times 10^{-5}$ | $3.28 \times 10^{-6}$  |
| <b>Å by</b>            | $10^{-10}$        | $10^{-8}$ | $10^{-7}$ | $10^{-4}$          | 1                   | $3.94 \times 10^{-9}$ | $3.28 \times 10^{-10}$ |
| <b>in by</b>           | 0.0254            | 2.540     | 25.40     | $2.54 \times 10^4$ | $2.54 \times 10^8$  | 1                     | 0.0833                 |
| <b>ft by</b>           | 0.305             | 30.48     | 304.8     | 304 800            | $3.048 \times 10^9$ | 12                    | 1                      |

1 angstrom Å = 0.1 nm  
                   = 0.000 0001 mm  
                   = 0.000 000 003 937 in  
 1 m = 1.094 yd  
 1 yd = 0.914 m  
 1 km = 0.621 mile  
 1 mile = 5280 ft  
           = 1760 yd  
           = 1.609 km



**Area**

|                          | <i>To obtain:</i><br><b>m<sup>2</sup></b> | <b>in<sup>2</sup></b> | <b>ft<sup>2</sup></b> | <b>cm<sup>2</sup></b> | <b>mm<sup>2</sup></b> |
|--------------------------|-------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <i>Multiply no. of</i>   |                                           |                       |                       |                       |                       |
| <b>m<sup>2</sup> by</b>  | 1                                         | 1550                  | 10.76                 | 10 000                | 10 <sup>6</sup>       |
| <b>in<sup>2</sup> by</b> | $6.452 \times 10^{-4}$                    | 1                     | $6.94 \times 10^{-3}$ | 6.452                 | 645.2                 |
| <b>ft<sup>2</sup> by</b> | 0.0929                                    | 144                   | 1                     | 929.0                 | 92 903                |
| <b>cm<sup>2</sup> by</b> | 0.0001                                    | 0.155                 | 0.001                 | 1                     | 100                   |
| <b>mm<sup>2</sup> by</b> | 10 <sup>-6</sup>                          | 0.001 55              | 0.000 01              | 0.01                  | 1                     |

1 cm<sup>2</sup> = 0.155 in<sup>2</sup>  
 1 m<sup>2</sup> = 1.196 yd<sup>2</sup>  
 1 km<sup>2</sup> = 247.104 acres  
           = 0.386 square mile  
 1 yd<sup>2</sup> = 0.836 m<sup>2</sup>  
 1 square mile = 259.0 hectares

**Mass**

|                        | <i>To obtain:</i><br><b>g</b> | <b>kg</b>              | <b>gr</b> | <b>oz</b>              | <b>lb</b>              |
|------------------------|-------------------------------|------------------------|-----------|------------------------|------------------------|
| <i>Multiply no. of</i> |                               |                        |           |                        |                        |
| <b>g by</b>            | 1                             | 0.001                  | 15.432    | 0.035 27               | 0.002 20               |
| <b>kg by</b>           | 1000                          | 1                      | 15 432    | 35.27                  | 2.205                  |
| <b>gr by</b>           | 0.0648                        | $6.480 \times 10^{-5}$ | 1         | $2.286 \times 10^{-3}$ | $1.429 \times 10^{-4}$ |
| <b>oz by</b>           | 28.35                         | 0.028 35               | 437.5     | 1                      | 0.0625                 |
| <b>lb by</b>           | 453.59                        | 0.4536                 | 7000      | 16                     | 1                      |

1 short ton = 2000 lb  
               = 0.892 857 long ton  
               = 907.1846 kg  
               = 0.907 1846 t

1 tonne (t) = 1000 kg  
               = 2204.623 lb  
               = 1.102 31 short tons  
               = 0.984 2107 long ton

1 long ton = 2240 lb  
               = 1.12 short tons  
               = 1016.047 kg  
               = 1.016 047 t

## Volume

|                                                                                                      | <i>To obtain:</i><br><b>ft<sup>3</sup></b> | <b>Imp gal</b>                                                                                                                                    | <b>litres</b> | <b>cm<sup>3</sup></b> | <b>m<sup>3</sup></b>  |
|------------------------------------------------------------------------------------------------------|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------------------|-----------------------|
| <i>Multiply no. of</i>                                                                               |                                            |                                                                                                                                                   |               |                       |                       |
| <b>ft<sup>3</sup> by</b>                                                                             | 1                                          | 6.229                                                                                                                                             | 28.32         | 28 320                | 0.0283                |
| <b>Imp gal by</b>                                                                                    | 0.1605                                     | 1                                                                                                                                                 | 4.546         | 4546                  | $4.55 \times 10^{-3}$ |
| <b>litres by</b>                                                                                     | 0.035 31                                   | 0.220                                                                                                                                             | 1             | 1000                  | $1 \times 10^{-3}$    |
| <b>cm<sup>3</sup> by</b>                                                                             | $3.531 \times 10^{-5}$                     | $2.20 \times 10^{-4}$                                                                                                                             | 0.001         | 1                     | $10^{-6}$             |
| <b>m<sup>3</sup> by</b>                                                                              | 35.31                                      | 220                                                                                                                                               | 1000          | $10^6$                | 1                     |
| <hr/>                                                                                                |                                            |                                                                                                                                                   |               |                       |                       |
| 1 cm <sup>3</sup> = 0.061 023 7 in <sup>3</sup> = 1 ml<br>= 0.035 1951 fl oz<br>= 0.033 814 US fl oz |                                            | 1 ft <sup>3</sup> = 1728 in <sup>3</sup><br><br>1 fl oz = 1.7339 in <sup>3</sup><br>= 28.413 cm <sup>3</sup> or ml<br>= 0.960 76 US fl oz         |               |                       |                       |
| 1 m <sup>3</sup> = 264.172 US gal                                                                    |                                            |                                                                                                                                                   |               |                       |                       |
| 1 litre = 0.264 172 US gal<br>= 35.195 fl oz<br>= 33.814 US fl oz                                    |                                            | 1 Imp gal = 160 fl oz<br>= 277.42 in <sup>3</sup><br>= 1.2010 US gal<br>= 153.72 US fl oz<br>= 4546.1 cm <sup>3</sup> or ml<br>= 4.546 litres     |               |                       |                       |
| 1 in <sup>3</sup> = 16.3871 cm <sup>3</sup> or ml<br>= 0.576 744 fl oz<br>= 0.554 113 US fl oz       |                                            | 1 US gal = 231 in <sup>3</sup><br>= 128 US fl oz<br>= 133.23 UK fl oz<br>= 0.832 67 Imp gal<br>= 3785.41 cm <sup>3</sup> or ml<br>= 3.7854 litres |               |                       |                       |

## Density

|                                                                       | <i>To obtain:</i><br><b>g/cm<sup>3</sup></b> | <b>lb/ft<sup>3</sup></b> | <b>lb/Imp gal</b> | <b>lb/US gal</b> |
|-----------------------------------------------------------------------|----------------------------------------------|--------------------------|-------------------|------------------|
| <i>Multiply no. of</i>                                                |                                              |                          |                   |                  |
| <b>g/cm<sup>3</sup> by</b>                                            | 1                                            | 62.43                    | 10.02             | 8.345            |
| <b>lb/ft<sup>3</sup> by</b>                                           | 0.016 02                                     | 1                        | 0.1605            | 0.1337           |
| <b>lb/Imp gal by</b>                                                  | 0.100                                        | 6.229                    | 1                 | 1.2010           |
| <b>lb/US gal by</b>                                                   | 0.1198                                       | 7.481                    | 0.832 67          | 1                |
| <hr/>                                                                 |                                              |                          |                   |                  |
| 1 mg/m <sup>3</sup> = 1000 mg/litre<br>= 35.314 mg/ft <sup>3</sup>    |                                              |                          |                   |                  |
| 1 mg/ft <sup>3</sup> = 28.32 mg/litre<br>= 0.028 32 mg/m <sup>3</sup> |                                              |                          |                   |                  |
| 1 lb/Imp gal = 1.2010 lb/US gal<br>1 lb/US gal = 0.832 67 lb/Imp gal  |                                              |                          |                   |                  |

**Viscosity****Dynamic** (20 °C)

|                                         |                  |                                  |
|-----------------------------------------|------------------|----------------------------------|
| centipoise                              | $\times 0.001$   | $= \text{N s/m}^2 = \text{Pa s}$ |
| newton second per $\text{m}^2$          | $\times 1000$    | $= \text{centipoise}$            |
| poise                                   | $\times 0.1$     | $= \text{N s/m}^2 = \text{Pa s}$ |
| pound force second<br>per $\text{ft}^2$ | $\times 47\,880$ | $= \text{centipoise}$            |
|                                         | $\times 47.880$  | $= \text{Pa s}$                  |

**Kinematic** (20 °C)

|                         |                    |                           |
|-------------------------|--------------------|---------------------------|
| centistoke              | $\times 1$         | $= \text{mm}^2/\text{s}$  |
| $\text{ft}^2/\text{hr}$ | $\times 25.807$    | $= \text{centistokes}$    |
|                         | $\times 0.092\,90$ | $= \text{m}^2/\text{hr}$  |
| $\text{m}^2/\text{hr}$  | $\times 10.764$    | $= \text{ft}^2/\text{hr}$ |

**Pressure**

|                             | <i>To obtain:</i>          |                            |                       |                      |                             |                    |
|-----------------------------|----------------------------|----------------------------|-----------------------|----------------------|-----------------------------|--------------------|
|                             | bar                        | MPa<br>( $\text{N/mm}^2$ ) | atm                   | mm Hg                | psi<br>( $\text{lb/in}^2$ ) | lb/ft <sup>2</sup> |
| <i>Multiply no. of</i>      |                            |                            |                       |                      |                             |                    |
| <b>bar</b> by               | 1                          | 0.1                        | 1.013 25              | $7.5006 \times 10^2$ | 14.5038                     | 2088.54            |
| <b>MPa</b> by               | 10                         | 1                          | 10.1325               | $7.5006 \times 10^3$ | 145.0377                    | 20 885.4           |
| <b>atm</b> by               | 0.986 9233                 | 0.098 6923                 | 1                     | 760.0                | 14.696                      | 2116               |
| <b>mm Hg</b> by             | $133.322 \times 10^{-5}$   | $133.322 \times 10^{-6}$   | 0.0013                | 1                    | 0.019 34                    | 2.785              |
| <b>psi</b> by               | $6.894\,76 \times 10^{-2}$ | $6.894\,76 \times 10^{-3}$ | 0.068                 | 51.71                | 1                           | 144                |
| <b>lb/ft<sup>2</sup></b> by | $4.788 \times 10^{-4}$     | $0.4788 \times 10^{-4}$    | $4.72 \times 10^{-4}$ | 0.359                | 0.0069                      | 1                  |

**Radiant energy units**

|                        | <i>To obtain:</i>  |           |           |                    |                       |
|------------------------|--------------------|-----------|-----------|--------------------|-----------------------|
|                        | erg                | joule     | W s       | W s                | g cal                 |
| <i>Multiply no. of</i> |                    |           |           |                    |                       |
| <b>erg</b> by          | 1                  | $10^{-7}$ | $10^{-7}$ | 0.1                | $2.39 \times 10^{-8}$ |
| <b>joule</b> by        | $10^7$             | 1         | 1         | $10^6$             | 0.239                 |
| <b>W s</b> by          | $10^7$             | 1         | 1         | $10^6$             | 0.239                 |
| <b>W s</b> by          | 10                 | $10^{-6}$ | $10^{-6}$ | 1                  | $2.39 \times 10^{-7}$ |
| <b>g cal</b> by        | $4.19 \times 10^7$ | 4.19      | 4.19      | $4.19 \times 10^6$ | 1                     |

**Flow rates**

|                              | <i>To obtain:</i><br>litres/min | m <sup>3</sup> /hr | Imp gal/min | US gal/min | ft <sup>3</sup> /min | ft <sup>3</sup> /s    |
|------------------------------|---------------------------------|--------------------|-------------|------------|----------------------|-----------------------|
| <i>Multiply no. of</i>       |                                 |                    |             |            |                      |                       |
| <b>litres/min</b> by         | 1                               | 0.06               | 0.2200      | 0.2642     | 0.0353               | $5.89 \times 10^{-4}$ |
| <b>m<sup>3</sup>/hr</b> by   | 16.67                           | 1                  | 3.7         | 4.4        | 0.588                | $9.89 \times 10^{-3}$ |
| <b>Imp gal/min</b> by        | 4.55                            | 0.273              | 1           | 1.2010     | 0.1605               | $2.67 \times 10^{-3}$ |
| <b>US gal/min</b> by         | 3.78                            | 0.227              | 0.832 67    | 1          | 0.1338               | $2.23 \times 10^{-3}$ |
| <b>ft<sup>3</sup>/min</b> by | 28.32                           | 1.699              | 6.23        | 7.50       | 1                    | 0.016 67              |
| <b>ft<sup>3</sup>/s</b> by   | 1699                            | 102                | 373.7       | 448.8      | 60                   | 1                     |

**Energy/unit area  
(dose units)**

|                                | <i>To obtain:</i><br>erg/cm <sup>2</sup> | joule/cm <sup>2</sup> | W s/cm <sup>2</sup> | W s/cm <sup>2</sup> | g cal/cm <sup>2</sup> |
|--------------------------------|------------------------------------------|-----------------------|---------------------|---------------------|-----------------------|
| <i>Multiply no. of</i>         |                                          |                       |                     |                     |                       |
| <b>erg/cm<sup>2</sup></b> by   | 1                                        | $10^{-7}$             | $10^{-7}$           | 0.1                 | $2.39 \times 10^{-8}$ |
| <b>joule/cm<sup>2</sup></b> by | $10^7$                                   | 1                     | 1                   | $10^6$              | 0.239                 |
| <b>W s/cm<sup>2</sup></b> by   | $10^7$                                   | 1                     | 1                   | $10^6$              | 0.239                 |
| <b>W s/cm<sup>2</sup></b> by   | 10                                       | $10^{-6}$             | $10^{-6}$           | 1                   | $2.39 \times 10^{-7}$ |
| <b>g cal/cm<sup>2</sup></b> by | $4.19 \times 10^7$                       | 4.19                  | 4.19                | $4.19 \times 10^6$  | 1                     |

**Concentration**

|                                               |            |                           |
|-----------------------------------------------|------------|---------------------------|
| mg/litre in water<br>(specific gravity = 1.0) | × 1.0      | = ppm or g/m <sup>3</sup> |
|                                               | × 0.001    | = g/litre                 |
|                                               | × 0.070157 | = grains per Imp gal      |
|                                               | × 0.058418 | = grains per US gal       |
|                                               | × 6.95     | = lb per million Imp gal  |
|                                               | × 8.35     | = lb per million US gal   |
| mg/kg                                         | × 0.002    | = lb/ton (short)          |
|                                               | × 0.0018   | = lb/ton (long)           |

### Emission rates

|                        | <i>To obtain:</i><br>g/s | g/min    | kg/hr                   | kg/day   | lb/min                  | lb/hr                   | lb/day |
|------------------------|--------------------------|----------|-------------------------|----------|-------------------------|-------------------------|--------|
| <i>Multiply no. of</i> |                          |          |                         |          |                         |                         |        |
| <b>g/s</b> by          | 1.0                      | 60.0     | 3.6                     | 86.40    | 0.132 28                | 7.9367                  | 190.48 |
| <b>g/min</b> by        | 0.016 667                | 1.0      | 0.06                    | 1.4400   | $2.2046 \times 10^{-3}$ | 0.132 28                | 3.1747 |
| <b>kg/hr</b> by        | 0.277 78                 | 16.667   | 1.0                     | 24.000   | 0.036 744               | 2.2046                  | 52.911 |
| <b>kg/day</b> by       | 0.011 574                | 0.694 44 | 0.041 667               | 1.0      | $1.5310 \times 10^{-3}$ | $9.1860 \times 10^{-2}$ | 2.2046 |
| <b>lb/min</b> by       | 7.5598                   | 453.59   | 27.215                  | 653.17   | 1.0                     | 60.0                    | 1440   |
| <b>lb/hr</b> by        | 0.126 00                 | 7.5598   | 0.453 59                | 10.886   | $1.6667 \times 10^{-2}$ | 1.0                     | 24.0   |
| <b>lb/day</b> by       | $5.2499 \times 10^{-3}$  | 0.314 99 | $1.8900 \times 10^{-2}$ | 0.453 59 | $6.9444 \times 10^{-4}$ | $4.1667 \times 10^{-2}$ | 1.0    |

### Heat, energy or work

|                        | <i>To obtain:</i><br>joule | ft lb              | kW hr                  | hp hr                  | kcal                  | cal     | Btu                    |
|------------------------|----------------------------|--------------------|------------------------|------------------------|-----------------------|---------|------------------------|
| <i>Multiply no. of</i> |                            |                    |                        |                        |                       |         |                        |
| <b>joules</b> by       | 1                          | 0.737              | $2.773 \times 10^{-7}$ | $3.725 \times 10^{-7}$ | $2.39 \times 10^{-4}$ | 0.2390  | $9.478 \times 10^{-4}$ |
| <b>ft lb</b> by        | 1.356                      | 1                  | $3.766 \times 10^{-7}$ | $5.05 \times 10^{-7}$  | $3.24 \times 10^{-4}$ | 0.3241  | $1.285 \times 10^{-3}$ |
| <b>kW hr</b> by        | $3.6 \times 10^6$          | $2.66 \times 10^6$ | 1                      | 1.341                  | 860.57                | 860 565 | 3412                   |
| <b>hp hr</b> by        | $2.68 \times 10^6$         | $1.98 \times 10^6$ | 0.7455                 | 1                      | 641.62                | 641 615 | 2545                   |
| <b>kcal</b> by         | 4184                       | 3086               | $1.162 \times 10^{-3}$ | $1.558 \times 10^{-3}$ | 1                     | 1000    | 3.9657                 |
| <b>cal</b> by          | 4.184                      | 3.086              | $1.162 \times 10^{-6}$ | $1.558 \times 10^{-6}$ | 0.001                 | 1       | 0.003 97               |
| <b>Btu</b> by          | 1055                       | 778.16             | $2.930 \times 10^{-4}$ | $3.93 \times 10^{-4}$  | 0.252                 | 252     | 1                      |

**Velocity**

|                        | <i>To obtain:</i><br><b>cm/s</b> | <b>m/s</b> | <b>km/hr</b> | <b>ft/s</b> | <b>ft/min</b> | <b>mph</b> |
|------------------------|----------------------------------|------------|--------------|-------------|---------------|------------|
| <i>Multiply no. of</i> |                                  |            |              |             |               |            |
| <b>cm/s by</b>         | 1                                | 0.01       | 0.036        | 0.0328      | 1.968         | 0.022 37   |
| <b>m/s by</b>          | 100                              | 1          | 3.6          | 3.281       | 196.85        | 2.237      |
| <b>km/hr by</b>        | 27.78                            | 0.2778     | 1            | 0.9113      | 54.68         | 0.6214     |
| <b>ft/s by</b>         | 30.48                            | 0.3048     | 18.29        | 1           | 60            | 0.6818     |
| <b>ft/min by</b>       | 0.5080                           | 0.005 08   | 0.0183       | 0.0166      | 1             | 0.011 36   |
| <b>mph by</b>          | 44.70                            | 0.4470     | 1.609        | 1.467       | 88            | 1          |

1 km/hr = 0.277 778 m/s  
           = 0.621 371 miles/hr  
           = 0.911 344 ft/s

1 ft/s = 0.681 818 miles/hr

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It is impractical to catalogue all relevant publications but the following is a selection of useful sources of information relating to hazardous substances. The scope of legislation is restricted to industrial sources of hazardous chemicals; excluded are pollution by domestic fires, emissions from road vehicles and other means of transport, etc. Some proposals for legislation will have now become enacted whereas others may be dropped. Some statutory instruments will have been repealed by subsequent versions. When investigating incidents, complaints etc. it is important to be aware of the legislation/guidance available at the time of the events. For this reason the selected legislation listed demonstrates the requirements in vogue at, or after, the time of publication of the first edition, even though many will have since been updated or repealed.

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## UK legislation on dangerous substances

### *Selected acts of parliament*

Environmental Protection Act 1990  
 Radioactive Material (Road Transport) Act 1991  
 Radioactive Substances Act 1993  
 The Environment Act 1995  
 The Health and Safety at Work etc. Act 1974



*Selected statutory instruments*

|              |                                                                                                 |
|--------------|-------------------------------------------------------------------------------------------------|
| SI 1962/2645 | Radioactive Substances (Exhibitions) Exemption Order                                            |
| SI 1962/2646 | Radioactive Substances (Storage and Transit) Exemption Order                                    |
| SI 1962/2648 | Radioactive Substances (Phosphatic Substances, Rare Earths, etc.) Exemption Order               |
| SI 1962/2649 | Radioactive Substances (Lead) Exemption Order                                                   |
| SI 1962/2710 | Radioactive Substances (Uranium and Thorium) Exemption Order                                    |
| SI 1962/2711 | Radioactive Substances (Prepared Uranium and Thorium Compounds) Order                           |
| SI 1962/2712 | Radioactive Substances (Geological Specimens) Exemption Order                                   |
| SI 1963/1831 | Radioactive Substances (Waste Closed Sources) Exemption Order                                   |
| SI 1963/1832 | Radioactive Substances (Schools, etc.) Exemption Order                                          |
| SI 1963/1836 | Radioactive Substances (Precipitated Phosphate) Exemption Order                                 |
| SI 1963/1832 | Radioactive Substances (Schools, etc.) Exemption Order                                          |
| SI 1967/1797 | Radioactive Substances (Electronic Valves) Exemption Order                                      |
| SI 1980/953  | Radioactive Substances (Smoke Detectors) Exemption Order                                        |
| SI 1980/1248 | Control of Lead at Work Regulations                                                             |
| SI 1982/1357 | The Notification of Installations Handling Hazardous Substances Regulations                     |
| SI 1983/1649 | Asbestos (Licensing) Regulations                                                                |
| SI 1983/1140 | The Classification and Labelling of Explosives Regulations                                      |
| SI 1984/1890 | Freight Containers (Safety Convention) Regulations                                              |
| SI 1985/1047 | Radioactive Substances (Gaseous Tritium Light Devices) Exemption Order                          |
| SI 1985/1048 | Radioactive Substances (Luminous Articles) Exemption Order                                      |
| SI 1985/1049 | Radioactive Substances (Testing Instruments) Exemption Order                                    |
| SI 1985/2042 | Asbestos Product (Safety) Regulations                                                           |
| SI 1986/1002 | Radioactive Substances (Substances of Low Activity) Exemption Order                             |
| SI 1986/1510 | Control of Pesticides Regulations                                                               |
| SI 1987/1979 | Asbestos Products (Safety) (Amendment) Regulations                                              |
| SI 1987/37   | Health and Safety – The Dangerous Substances in Harbour Areas Regulations                       |
| SI 1987/2115 | Control of Asbestos at Work Regulations                                                         |
| SI 1988/819  | Collection and Disposal of Waste Regulations                                                    |
| SI 1988/1655 | Health and Safety – The Docks Regulations                                                       |
| SI 1989/1156 | Trade Effluents (Prescribed Processes and Substances) Regulations                               |
| SI 1990/556  | Control of Asbestos in Air Regulations                                                          |
| SI 1990/2504 | Radioactive Substances (Appeals) Regulations                                                    |
| SI 1990/2512 | Radioactive Substances (Hospitals) Exemption Order                                              |
| SI 1991/447  | Radioactive Substances (Smoke Detectors) Exemption (Amendment) Order                            |
| SI 1991/836  | Environmental Protection (Prescribed Processes and Substances) Regulations                      |
| SI 1992/31   | Environmental Protection (Controls on Injurious Substances) Regulations                         |
| SI 1992/43   | Road Traffic (Carriage of Dangerous Substances in Road Tankers and Tank Containers) Regulations |
| SI 1992/647  | Radioactive Substances (Substances of Low Activity) Exemption (Amendment) Order                 |
| SI 1992/656  | Planning (Hazardous Substances) Regulations                                                     |
| SI 1992/1583 | Environmental Protection (Controls on Injurious Substances) (No. 2) Regulations                 |
| SI 1992/1685 | Radioactive Substances (Records of Convictions) Regulations                                     |
| SI 1992/2617 | The Environmental Protection Act 1990 (Modification of Section 112) Regulations                 |
| SI 1992/2997 | Public Information for Radiation Emergencies Regulations                                        |
| SI 1992/3067 | Asbestos (Prohibitions) Regulations                                                             |
| SI 1992/3068 | Control of Asbestos at Work (Amendment) Regulations                                             |
| SI 1992/3217 | The Genetically Modified Organisms (Contained Use) Regulations                                  |
| SI 1992/3280 | The Genetically Modified Organisms (Deliberate Release) Regulations                             |
| SI 1993/1    | Environmental Protection (Controls on Injurious Substances) Regulations                         |
| SI 1993/15   | The Genetically Modified Organisms (Contained Use) Regulations                                  |
| SI 1993/152  | The Genetically Modified Organisms (Deliberate Release) Regulations                             |
| SI 1993/1643 | Environmental Protection (Controls on Injurious Substances) (No. 2) Regulations                 |
| SI 1993/3031 | Transfrontier Shipment of Radioactive Waste Regulations                                         |
| SI 1994/199  | Environmental Protection (Non-Refillable Refrigerant Containers) Regulations                    |
| SI 1994/232  | Batteries and Accumulators (Containing Dangerous Substances) Regulations                        |
| SI 1994/2844 | Dangerous Substances and Preparations (Safety) (Consolidation) Regulations                      |
| SI 1994/3247 | Chemical (Hazard Information and Packaging for Supply) Regulations                              |

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|--------------|---------------------------------------------------------------------------------------------------------------------------------|
| SI 1995/304  | The Genetically Modified Organisms (Deliberate Release) Regulations                                                             |
| SI 1995/2395 | Radioactive Substances (Hospitals) Exemption (Amendment) Order                                                                  |
| SI 1996/967  | The Genetically Modified Organisms (Contained Use) (Amendment) Regulations                                                      |
| SI 1996/1092 | Chemicals (Hazard Information and Packaging for Supply) (Amendment) Regulations                                                 |
| SI 1996/1106 | The Genetically Modified Organisms (Risk Assessment) (Records and Exemptions) Regulations                                       |
| SI 1996/1350 | Radioactive Material (Road Transport) (Great Britain) Regulations                                                               |
| SI 1996/2075 | Health and Safety at Work etc. Act 1974 (Application to Environmentally Hazardous Substances) Regulations                       |
| SI 1996/2089 | The Carriage of Dangerous Goods by Rail Regulations                                                                             |
| SI 1996/2090 | Packaging, Labelling and Carriage of Radioactive Material by Rail Regulations                                                   |
| SI 1996/2092 | Carriage of Dangerous Goods (Classification, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations |
| SI 1996/2093 | Health and Safety – The Carriage of Explosives by Road Regulations                                                              |
| SI 1996/2094 | The Carriage of Dangerous Goods by Road (Driver Training) Regulations                                                           |
| SI 1996/2095 | The Carriage of Dangerous Goods by Road Regulations                                                                             |
| SI 1996/2635 | Dangerous Substances and Preparations (Safety) (Consolidation) (Amendment) Regulations                                          |
| SI 1997/1460 | Chemicals (Hazard Information and Packaging for Supply) (Amendment) Regulations                                                 |
| SI 1997/1900 | The Genetically Modified Organisms (Deliberate Release and Risk Assessment) (Amendment) Regulations                             |
| SI 1997/2367 | Marine Pollution – Merchant Shipping – Safety – The Merchant Shipping (Dangerous Goods and Marine Pollutants) Regulations       |
| SI 1998/545  | Environmental Protection (Control of Hexachloroethane) Regulations                                                              |
| SI 1998/767  | Environmental Protection (Prescribed Processes and Substances) (Amendment) (Hazardous Waste Incineration) Regulations           |
| SI 1998/1548 | The Genetically Modified Organisms (Contained Use) (Amendment) Regulations                                                      |
| SI 1998/2885 | The Carriage of Dangerous Goods (Amendment) Regulations                                                                         |
| SI 1998/3106 | The Chemical (Hazard Information and Packaging for Supply) (Amendments) Regulations                                             |
| SI 1998/3233 | Asbestos (Licensing) (Amendment) Regulations                                                                                    |
| SI 1998/3235 | Control of Asbestos at Work (Amendment) Regulations                                                                             |
| SI 1999/40   | Health and Safety at Work etc. Act 1974 (Application to Environmentally Hazardous Substances) (Amendment) Regulations           |
| SI 1999/197  | The Chemical (Hazard Information and Packaging for Supply) (Amendment) Regulations                                              |
| SI 1999/257  | The Transport of Dangerous Goods (Safety Advisers) Regulations                                                                  |
| SI 1999/303  | Carriage of Dangerous Goods (Amendment) Regulations                                                                             |
| SI 1999/336  | Merchant Shipping – Safety – The Merchant Shipping (Carriage of Cargos) Regulations                                             |
| SI 1999/396  | Environmental Protection Act 1990 (Extension of Section 140) Regulations                                                        |
| SI 1999/437  | The Control of Substances Hazardous to Health Regulations 1999                                                                  |
| SI 1999/743  | The Control of Major Accident Hazards Regulations                                                                               |
| SI 1999/981  | Planning (Control of Major Accident Hazards) Regulations                                                                        |
| SI 1999/2084 | Dangerous Substances and Preparations (Safety) (Consolidation) (Amendment) Regulations                                          |
| SI 1999/2373 | Asbestos (Prohibitions) (Amendment) Regulations                                                                                 |
| SI 1999/2977 | Asbestos (Prohibitions) (Amendment) (No. 2) Regulations                                                                         |
| SI 1999/2978 | Road Vehicles (Brake Linings Safety) Regulations                                                                                |
| SI 1999/3244 | Environmental Protection (Controls on Injurious Substances) Regulations                                                         |
| SI 1999/3106 | Health and Safety – The Good Laboratory Practice Regulations                                                                    |
| SI 1999/3165 | Chemicals (Hazard Information and Packaging for Supply) (Amendment) (No. 2) Regulations                                         |
| SI 1999/3193 | Dangerous Substances and Preparations (Safety) (Consolidation) (Amendment) (No. 2) Regulations                                  |
| SI 1999/3194 | Chemicals (Hazard Information and Packaging for Supply) (Amendment) (No. 3) Regulations                                         |
| SI 1999/3232 | Health and Safety – The Ionising Radiations Regulations                                                                         |
| SI 2000/128  | Pressure Systems Safety Regulations                                                                                             |
| SI 2000/1043 | Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) (England and Wales) Regulations |

## European legislation on dangerous substances

### *Selected regulations*

|          |                                                                                                                                                                                                                          |
|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2455/92  | Regulation on the export and import of dangerous chemicals                                                                                                                                                               |
| 3600/92  | Regulation on the implementation of the first stage of the programme referred to in Directive 91/414/EEC on the placing of plant protection products on the market                                                       |
| 793/93   | Regulation on the evaluation of existing substances                                                                                                                                                                      |
| 933/94   | Regulation on the laying down of active substances of plant protection products and designating rapporteur Member States for the implementation of Regulation 3600/92                                                    |
| 1179/94  | Regulation on priority substances under Regulation 793/93                                                                                                                                                                |
| 1488/94  | Regulation on the assessment of risks in accordance with Regulation 793/93                                                                                                                                               |
| 3135/94  | Regulation amending 2455/92 on the export and import of dangerous chemicals                                                                                                                                              |
| 2230/95  | Regulation amending Regulation 933/94 on the laying down of active substances of plant protection products and designating rapporteur Member States for the implementation of Regulation 3600/92                         |
| 1492/96  | Regulation amending Regulation 2455/92 on the import and export of dangerous chemicals                                                                                                                                   |
| 1199/97  | Regulation amending Regulation 3600/92 on the implementation of the first stage of the programme referred to in Directive 91/414/EEC on the placing of plant protection products on the market                           |
| 1237/97  | Regulation amending Annex II to Regulation 2455/92 concerning the export and import of certain dangerous chemicals                                                                                                       |
| 2247/98  | Regulation amending Regulation 2455/92 concerning the export and import of certain dangerous chemicals                                                                                                                   |
| 1493/93  | Regulation 1493/93 on shipments of radioactive substances between Member States                                                                                                                                          |
| 1972/99  | Regulation amending Regulation (EEC) No. 3600/92 on the implementation of the first stage of the programme of work referred to in Directive 91/414/EEC concerning the placing of plant protection products on the market |
| 645/2000 | Regulation on rules for provisions of Directive 86/362/EEC and Directive 90/642/EEC on the maximum levels of pesticide residues                                                                                          |

### *Selected directives*

|            |                                                                                                                                                          |
|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 67/548/EEC | Directive on the classification, etc. of dangerous substances                                                                                            |
| 73/404/EEC | Directive relating to detergents                                                                                                                         |
| 75/439/EEC | Directive on the disposal of waste oils                                                                                                                  |
| 76/116/EEC | Directive on the approximation of the laws relating to fertilizers                                                                                       |
| 76/403/EEC | Directive on PCBs                                                                                                                                        |
| 76/464/EEC | Directive on dangerous substances discharged into water                                                                                                  |
| 76/769/EEC | Directive on the marketing and use of dangerous substances                                                                                               |
| 76/895/EEC | Directive on pesticide residues in and on fruit and vegetables                                                                                           |
| 77/93/EEC  | Directive on protective measures against the introduction of organisms harmful to plants or plant products and against their spread within the community |
| 78/176/EEC | Directive on waste from the titanium dioxide industry                                                                                                    |
| 78/319/EEC | Directive on toxic and dangerous waste                                                                                                                   |
| 79/831/EEC | Directive sixth amendment to Directive 67/548/EEC                                                                                                        |
| 82/176/EEC | Directive on Mercury (Chlor-alkali electrolysis industry)                                                                                                |
| 82/501/EEC | Directive on major accident hazards (Seveso Directive)                                                                                                   |
| 82/806/EEC | Directive amending Directive 76/769/EEC (benzene)                                                                                                        |
| 83/478/EEC | Directive amending Directive 76/769/EEC (asbestos)                                                                                                       |
| 83/513/EEC | Directive on cadmium                                                                                                                                     |
| 83/477/EEC | Directive on the protection of workers from exposure to asbestos at work                                                                                 |
| 84/156/EEC | Directive on mercury                                                                                                                                     |
| 84/491/EEC | Directive on hexachlorocyclohexane                                                                                                                       |
| 85/467/EEC | Directive amending (PCBs) Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations.       |
| 86/362/EEC | Directive on pesticide residues in and on cereals                                                                                                        |
| 86/363/EEC | Directive on pesticide residues in foodstuffs of animal origin                                                                                           |

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| 87/217/EEC   | Directive on pollution by asbestos                                                                                                                                      |
| 88/183/EEC   | Directive amending Directive 76/116/EEC in respect of fluid fertilizers                                                                                                 |
| 89/178/EEC   | Directive amending Directive 88/379/EEC relating to the classification, packaging and labelling of dangerous preparations                                               |
| 89/284/EEC   | Directive amending Directive 76/116/EEC in respect of the calcium, magnesium, sodium and sulphur content of fertilizers                                                 |
| 89/530/EEC   | Directive amending Directive 76/116/EEC in respect of the trace elements contained in fertilizers                                                                       |
| 89/677/EEC   | Directive amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances                                               |
| 89/684/EEC   | Directive on training for drivers of vehicles carrying dangerous goods                                                                                                  |
| 90/219/EEC   | Directive on the contained use of genetically modified micro-organisms                                                                                                  |
| 90/220/EEC   | Directive on the deliberate release into the environment of genetically modified organisms                                                                              |
| 90/394/EEC   | Directive on the protection of workers from the exposure from carcinogens at work                                                                                       |
| 90/492/EEC   | Directive amending Directive 88/379/EEC relating to the classification, packaging and labelling of dangerous preparations.                                              |
| 90/642/EEC   | Directive on pesticide on certain products of plant origin                                                                                                              |
| 91/132/EEC   | Directive amending Directive 74/63/EEC on animal nutrition                                                                                                              |
| 91/155/EEC   | Directive defining the detailed arrangements for the system of specific information relating to dangerous preparations with respect to the implementation of 88/379/EEC |
| 91/157/EEC   | Directive on batteries and accumulators                                                                                                                                 |
| 91/173/EEC   | Directive amending Directive 76/769/EEC on marketing and use of dangerous substances and preparations                                                                   |
| 91/188/EEC   | Directive amending 79/117/EEC on plant protection products                                                                                                              |
| 91/338/EEC   | Directive amending Directive 76/769/EEC on the marketing and use of dangerous substances                                                                                |
| 91/339/EEC   | Directive amending Directive 76/769/EEC on the marketing and use of dangerous substances                                                                                |
| 91/382/EEC   | Directive amending Directive 83/477/EEC on the protection of workers from exposure to asbestos at work                                                                  |
| 91/414/EEC   | Directive on plant protection products (marketing)                                                                                                                      |
| 91/689/EEC   | Directive on hazardous waste                                                                                                                                            |
| 92/32/EEC    | Directive amending Directive 67/548/EEC                                                                                                                                 |
| 92/3/EURATOM | Directive on the supervision and control of shipments of radioactive waste between Member States and into and out of the Community                                      |
| 93/18/EEC    | Directive amending Directive 88/379/EEC relating to the classification, packaging and labelling of dangerous preparations                                               |
| 93/69/EEC    | Directive adapting to technical progress Directive 76/116/EEC on the approximation of the laws relating to fertilizers                                                  |
| 93/71/EEC    | Directive amending Directive 91/414/EEC on plant protection products                                                                                                    |
| 93/75/EEC    | Directive on minimum requirements of tankers in Community ports                                                                                                         |
| 93/86/EEC    | Directive adapting to technical progress 91/157/EEC on batteries                                                                                                        |
| 94/15/EC     | Directive adapting to technical progress Directive 90/220/EC on the deliberate release into the environment of genetically modified organisms                           |
| 94/27/EC     | Directive amending 76/769/EEC on the marketing of dangerous substances                                                                                                  |
| 94/29/EC     | Directive amending 86/362/EEC and 86/363/EEC on pesticide residues                                                                                                      |
| 94/30/EC     | Directive amending 90/642/EEC on pesticide on products of plant origin                                                                                                  |
| 94/51/EC     | Directive adapting to technical progress Directive 90/219/EC on the contained use of genetically modified micro-organisms                                               |
| 94/63/EC     | Directive on the control of volatile organic compounds (VOC) emissions resulting from the storage of petrol and its distribution from terminals to petrol stations      |
| 94/48/EC     | Directive amending for the 13th time Directive 76/769/EEC                                                                                                               |
| 94/55/EC     | Directive on the transport of dangerous goods by road                                                                                                                   |
| 94/60/EC     | Directive amending for the 14th time 76/769/EEC                                                                                                                         |
| 94/69/EC     | Directive adapting to technical progress 67/548/EEC dangerous substances                                                                                                |
| 94/79/EC     | Directive amending Directive 91/414/EEC on plant protection products                                                                                                    |
| 95/35/EC     | Directive amending Directive 91/414/EEC concerning the placing of plant protection products on the market                                                               |
| 95/36/EC     | Directive amending Directive 91/414/EEC concerning the placing of plant protection products on the market                                                               |
| 95/38/EC     | Directive amending Directive 90/642/EEC on pesticides in products of plant origin                                                                                       |
| 95/39/EC     | Directive amending 86/362/EEC and 86/363/EEC on pesticides in foodstuffs of animal origin                                                                               |



- 95/50/EC Directive on uniform procedures for checks on the transport of dangerous goods by road
- 95/61/EC Directive amending Annex II to Directive 90/642/EEC relating to the fixing of maximum levels for pesticide residues in and on certain products of plant origin
- 95/543/EC Directive on the request from the UK to exempt certain transport operations from the application 89/684/EEC
- 96/12/EC Directive amending Directive 91/414/EEC concerning the placing of plant protection products on the market
- 96/28/EC Directive on adaptation of laws relating to fertilizers
- 96/29/EURATOM Directive laying down basic safety standards for the protection of workers and the general public against dangers arising from ionizing radiation
- 96/32/EC Directive amending the Pesticide Residue Directive (60/642/EEC)
- 96/33/EC Directive amending Directives 86/362/EEC and 86/363/EEC on pesticide residues
- 96/35/EC Directive on appointing safety advisers for the transport of dangerous goods
- 96/46/EC Directive amending Directive 91/414/EEC concerning the placing of plant protection products on the market
- 96/49/EC Directive on the transportation of dangerous goods by rail
- 96/54/EC Directive adapting to technical progress on the classification of dangerous substances Directive 67/548/EEC
- 96/55/EC Directive adapting to technical progress Annex I to Directive 76/769/EEC
- 96/56/EC Directive amending Directive 67/548/EEC on the approximation of the laws relating to the classification, packaging and labelling of dangerous substances
- 96/59/EC Directive on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT)
- 96/65/EC Directive on dangerous substances adapting the technical progress
- 96/82/EC Directive on the control of major-accident hazards involving dangerous substances
- 96/86/EC Directive adapting to technical progress Directive 94/55/EC on the approximation of the laws with regard to the transport of dangerous goods by road
- 96/94/EC Directive establishing a value for Directive 80/1107/EEC on the protection of workers from the risks from exposure to chemical, physical and biological agents
- 97/10/EC Directive adapting to technical progress Annex I to Directive 76/769/EEC on the approximation of the laws relating to restrictions on the marketing and use of certain dangerous substances and preparations
- 97/16/EC Directive amending Directive 76/769/EEC on restrictions on the marketing and use of dangerous substances and preparations
- 97/35/EC Directive adapting (for the second time) to technical progress Directive 90/220/EC on the deliberate release into the environment of genetically modified organisms
- 97/42/EC Directive amending Directive 90/394/EEC on the protection of workers from exposure to carcinogens at work
- 97/56/EC Directive amending for the 16th time Directive 76/769/EEC on dangerous substances and preparations
- 97/57/EC Directive establishing Annex VI for Directive 91/414/EEC regarding plant protection products
- 97/64/EC Directive amending Directive 79/769/EEC on dangerous substances lamps oils
- 97/69/EC Directive on the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances
- 97/71/EC Directive amending 86/362/EEC, 86/363/EEC and 90/642/EEC on the fixing of maximum levels for pesticide residues, etc.
- 97/865/EC Directive on the possible inclusion of various substance into Annex 1 of Directive 91/414 on plant protection products
- 98/3/EC Directive adapting to technical progress 76/116/EEC on the approximation of the laws relating to fertilizers
- 98/8/EC Directive concerning the placing of biocidal products on the market
- 98/55/EC Directive amending 93/75/EEC on the minimum requirements for vessels bound for or leaving Community ports, carrying dangerous or polluting goods
- 98/73/EC Directive adapting to technical progress for the 24th time 67/548/EEC on dangerous substances
- 98/74/EC Directive amending 93/75/EEC on the minimum requirements for vessels bound for or leaving Community ports, carrying dangerous or polluting goods
- 98/91/EC Directive on trailers for the transport of dangerous goods
- 98/98/EC Directive adapting to technical progress for the 25th time 67/548/EEC on dangerous substances
- 98/101/EC Directive adapting to technical progress 91/157/EEC on batteries and accumulators containing dangerous substances
- 98/676/EC Directive on the possible inclusion of various substances into Annex 1 of Directive 91/414 on plant protection products

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| 99/1/EC    | Directive including the active substance kresoxim-methyl in Annex I of 91/414/EEC concerning plant protection products                                                                                                |
| 99/13/EC   | Directive on limitation of emissions of volatile organic compounds (VOCs) due to the use of organic solvents in certain activities and installations                                                                  |
| 99/43/EC   | Directive amending for the 17th time Directive 76/769/EEC on the marketing and use of certain dangerous substances and preparations                                                                                   |
| 99/45/EC   | Directive concerning the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations                  |
| 99/57/EC   | Directive adapting Annex I to Directive 76/769/EEC on the marketing and use of certain dangerous substances and preparations (tin, PCP and cadmium)                                                                   |
| 99/65/EC   | Directive amending Directives 86/362/EEC and 90/642/EEC on the maximum levels for pesticide residues in and on cereals and certain products of plant origin including fruit and vegetables respectively               |
| 99/73/EC   | Directive including spiroxamine in Annex I to Council Directive 91/414/EEC for the placing of plant protection products on the market                                                                                 |
| 99/80/EC   | Directive including an active substance (azimsulfuron) in Annex I to Council Directive 91/414/EEC concerning the placing of plant protection products on the market                                                   |
| 99/47/EC   | Directive adapting for the second time to technical progress Council Directive 94/55/EC on the transport of dangerous goods by road                                                                                   |
| 99/48/EC   | Directive adapting for the second time to technical progress Directive 96/49/EC on the transport of dangerous goods by rail                                                                                           |
| 99/53/EC   | Directive amending Annex III to Directive 77/93/EEC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community |
| 99/77/EC   | Directive adapting for the sixth time Annex I to Directive 76/769/EEC on the marketing and use of certain dangerous substances and preparations (asbestos)                                                            |
| 2000/10/EC | Directive on the inclusion of fluroxypyr in Annex 1 of Directive 91/414/EEC on plant protection products                                                                                                              |
| 2000/21/EC | Directive concerning the list of legislation referred to in Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances                                                               |
| 2000/18/EC | Directive on minimum examination requirements for safety advisers for the transport of dangerous goods by road, rail or inland waterway                                                                               |
| 2000/32/EC | Directive adapting for the 26th time Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances                                                                                      |
| 2000/33/EC | Directive adapting for the 27th time Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances                                                                                      |

### *Selected Decisions*

|           |                                                                                                                                                                                                                                                      |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 94/785/EC | Decision on UK exemption from 89/684/EEC on training of drivers                                                                                                                                                                                      |
| 98/269/EC | Decision on the withdrawal of Dinoterb.                                                                                                                                                                                                              |
| 98/270/EC | Decision on the withdrawal of plant protection products containing Fenvalerate.                                                                                                                                                                      |
| 98/433/EC | Decision regarding a harmonized criteria for dispensations from 96/82/EC on major accident hazards                                                                                                                                                   |
| 98/685/EC | Decision on the Convention on the Transboundary Effects of Industrial Accidents                                                                                                                                                                      |
| 99/164/EC | Decision concerning the non-inclusion of DNOC in Annex I of Directive 91/414/EEC on plant protection products                                                                                                                                        |
| 99/237/EC | Decision on the possible inclusion of oxasulfuron in Annex I to Council Directive 91/414/EEC concerning the placing of plant-protection products on the market                                                                                       |
| 99/392/EC | Decision recognizing the dossiers for the possible inclusion of mesotrione, iodosulfuron-methyl-sodium, silthiopham and gliocladium catenulatum in Annex I to Directive 91/414/EEC concerning the placing of plant-protection products on the market |
| 99/462/EC | Decision 99/462/EC on the view of the possible inclusion of alanycarbe in Annex I to Directive 91/414/EEC concerning the placing of plant-protection products on the market                                                                          |
| 99/610/EC | Decision on the view of the possible inclusion of carvone in Annex I to Council Directive 91/414/EEC concerning the placing of plant-protection products on the market                                                                               |
| 99/636/EC | Decision authorizing the Member States to permit temporarily the marketing of forest reproductive material not satisfying the requirements of Directive 66/404/EEC                                                                                   |

|             |                                                                                                                                                                                                      |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2000/166/EC | Decision extending the possible time period for provisional authorizations of the new active substance quinoxifen                                                                                    |
| 2000/180/EC | Decision extending the possible time period for provisional authorizations of the new active substance pseudomonas chlororaphis                                                                      |
| 2000/181/EC | Decision on the view of the possible inclusion of thiacloprid, forchlorfenuron, thiamethoxam in Directive 91/414/EEC on the placing of plant-protection products on the market                       |
| 2000/210/EC | Decision on the view of the possible inclusion of spinosad in Annex I to Council Directive 91/414/EEC concerning the placing of plant-protection products on the market                              |
| 2000/233/EC | Decision on the withdrawal of authorizations for plant-protection products containing pyrazophos and non-inclusion in Directive 91/414/EEC on the placing of plant-protection products on the market |
| 2000/234/EC | Decision on the withdrawal of authorizations of plant protection products containing monolinuron and non-inclusion in Directive 91/414/EC                                                            |
| 2000/251/EC | Decision on the possible inclusion of RPA407213 (fenamidone) in Directive 91/414/EEC on the placing of plant-protection products on the market                                                       |
| 2000/320/EC | Decision authorizing Member States to permit temporarily the marketing of forest reproductive material not satisfying the requirements of Council Directive 66/404/EEC                               |
| 2000/358/EC | Decision extending time period for provisional authorizations of the new active substances flupyrsulfuron methyl, carfentrazone ethyl, prosulfuron, flurtamone, isoxaflutole                         |
| 2000/390/EC | Decision on the inclusion of EXP60707B (acetamiprid) in Annex I to Council Directive 91/414/EEC concerning the placing of plant-protection products on the market                                    |
| 2000/412/EC | Decision on the possible inclusion of IKF 916 (cyazofamid) in Annex I to Council Directive 91/414/EEC concerning the placing of plant protection products on the market                              |

### *Selected Proposed Legislation*

|            |                                                                                                                                                                   |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| COM(91)373 | Proposal on PCBs                                                                                                                                                  |
| COM(93)349 | Proposal concerning ionizing radiation                                                                                                                            |
| COM(94)573 | Proposal for a Directive on the approximation of the laws with regard to the transport of dangerous goods by rail                                                 |
| COM(94)579 | Proposal for a Regulation concerning the creation of a supplementary protection certificate for plant protection products                                         |
| COM(95)272 | Proposal to amend Directives 76/895/EEC, 86/362/EEC, 86/363/EEC and 90/642/EEC on the fixing of maximum pesticide residues in and on certain specified foodstuffs |
| COM(95)240 | Proposal on major-accident hazards involving dangerous substances                                                                                                 |
| COM(95)636 | Proposal to amend Directive 67/546/EEC on dangerous substance classification                                                                                      |
| COM(96)347 | Proposal on the classification, packaging and labelling of dangerous preparations                                                                                 |
| COM(96)513 | Proposal for a Directive amending Directive 79/769/EEC on dangerous substances and preparations                                                                   |
| COM(96)594 | Proposal for a Directive amending Directives 76/116/EEC, 80/876/EEC, 89/284/EEC and 89/530/EEC on the laws relating to fertilizers                                |
| COM(97)214 | Proposal to amend the Basel Convention                                                                                                                            |
| COM(97)330 | Proposal on the transboundary effects of industrial accidents.                                                                                                    |
| COM(97)738 | Proposal amending 76/769/EEC on the laws relating to restrictions on the marketing and use of certain dangerous substances and preparations                       |
| COM(97)604 | Proposal to amend 94/67/EC on incineration of hazardous waste                                                                                                     |
| COM(98)174 | Proposal for a Directive on the examination requirements for safety advisers for the transport of dangerous goods                                                 |
| COM(99)157 | Proposal for a Directive amending Directive 96/49/EC on the transport of dangerous goods by rail                                                                  |
| COM(99)158 | Proposal for a Directive amending Directive 94/55/EC on the transport of dangerous goods by road                                                                  |

### *Other documents*

|               |                                                                                        |
|---------------|----------------------------------------------------------------------------------------|
| OJ: C361/3/94 | Communication pursuant to 85/71/EEC and 67/548/EEC                                     |
| 96/199/EC     | Recommendation on the 1996 pesticide residue monitoring programme                      |
| OJ: C22/10/98 | On reference numbers for the notification of the export of certain dangerous chemicals |

OJ: L294/1/98  
99/829/Euratom

An Annex to Council Directive 96/49/EC with regard to the transport of dangerous goods by rail  
Recommendation on the application of Article 37 of the Euratom Treaty

## UK legislation on air pollution

### *Selected Acts of Parliament*

Health and Safety Act 1974 (Part 1)  
Highway Act 1980 Sections 161 and 161A  
Environmental Protection Act 1990  
Clean Air Act 1993  
Environment Act 1995

### *Selected Statutory Instruments*

|              |                                                                                                                           |
|--------------|---------------------------------------------------------------------------------------------------------------------------|
| SI 1958/498  | Dark Smoke (Permitted Periods) Regulations                                                                                |
| SI 1969/411  | Clean Air (Height of Chimneys) (Exemption) Regulations                                                                    |
| SI 1969/1262 | Clean Air (Arrestment Plant) (Exemption) Regulations                                                                      |
| SI 1969/1263 | Clean Air (Emissions of Dark Smoke) (Exemption) Regulations                                                               |
| SI 1971/161  | Clean Air (Measurement of Grit and Dust from Furnaces) Regulations                                                        |
| SI 1971/162  | Clean Air (Emission of Grit and Dust from Furnaces) Regulations                                                           |
| SI 1977/17   | Control of Atmosphere Pollution (Appeals) Regulations                                                                     |
| SI 1977/18   | Control of Atmospheric Pollution (Exempted Premises) Regulations                                                          |
| SI 1983/943  | Health and Safety (Emissions into the Atmosphere) Regulations                                                             |
| SI 1989/317  | Air Quality Standards Regulations                                                                                         |
| SI 1989/319  | Health and Safety (Emissions into the Atmosphere) (Amendment) Regulations                                                 |
| SI 1990/556  | Control of Asbestos in Air Regulations                                                                                    |
| SI 1991/472  | Environmental Protection (Prescribed Processes and Substances) Regulations                                                |
| SI 1991/507  | Environmental Protection (Application, Appeals and Registers) Regulations                                                 |
| SI 1991/513  | Environmental Protection (Authorization of Processes) (Determination Periods) Order                                       |
| SI 1991/1282 | Smoke Control Areas (Authorized Fuels) Regulations                                                                        |
| SI 1992/72   | Smoke Control Areas (Authorized Fuels) (Amendment) Regulations                                                            |
| SI 1992/2225 | Notification of Cooling Towers and Evaporative Condensers Regulations                                                     |
| SI 1993/2499 | Smoke Control Areas (Authorized Fuels) (Amendment) Regulations                                                            |
| SI 1994/199  | Environmental Protection (Non-Refillable Refrigerant Containers) Regulations                                              |
| SI 1994/440  | Ozone Monitoring and Information Regulations                                                                              |
| SI 1995/2644 | Statutory Nuisance (Appeals) Regulations                                                                                  |
| SI 1995/3146 | Air Quality Standards (Amendment) Regulations                                                                             |
| SI 1996/506  | Environmental Protection (Controls on Substances that Deplete the Ozone Layer) Regulations                                |
| SI 1996/1145 | Smoke Control Areas (Authorized Fuels) (Amendment) Regulations                                                            |
| SI 1996/2678 | The Environmental Protection (Prescribed Processes and Substances, etc.) (Amendment) (Petrol Vapour Recovery) Regulations |
| SI 1997/2658 | Smoke Control Areas (Authorized Fuels) (Amendment) Regulations                                                            |
| SI 1997/3043 | Air Quality Regulations                                                                                                   |
| SI 1998/767  | Environmental Protection (Prescribed Processes and Substances) (Amendment) (Hazardous Waste Incineration) Regulations     |
| SI 1998/2154 | Smoke Control Areas (Authorized Fuels) (Amendment) Regulations                                                            |
| SI 1998/3096 | Smoke Control Areas (Authorized Fuels) (Amendment No. 2) Regulations                                                      |
| SI 1999/3107 | Motor Fuel (Composition and Content) Regulations                                                                          |
| SI 2000/928  | The Air Quality (England) Regulations                                                                                     |
| SI 2000/1077 | Smoke Control Areas (Authorized Fuels) (Amendment) (England) Regulations                                                  |
| SI 2000/1460 | The Sulphur Content of Liquid Fuels (England and Wales) Regulations                                                       |

## European legislation on air pollution

### *Selected regulations*

3093/94                      Regulation replacing Regulation 594/91 on ozone depleting substances

### *Selected directives*

77/312/EEC                Directive on the biological screening of the population for lead  
80/779/EEC                Directive on air quality standards – sulphur dioxide  
82/884/EEC                Directive on air quality standards – lead concentrations  
84/360/EEC                Directive on air pollution from industrial plants  
85/203/EEC                Directive on air quality standards – nitrogen dioxide  
85/210/EEC                Directive on lead content of petrol  
87/217/EEC                Directive on pollution by asbestos  
88/609/EEC                Directive on large combustion plants  
89/369/EEC                Directive on new municipal waste incineration plants  
89/429/EEC                Directive on existing municipal waste incineration plants  
92/55/EEC                Directive on motor vehicle exhaust emission tests  
92/73/EEC                Directive on air pollution by ozone  
93/12/EEC                Directive on sulphur content of liquid fuels  
93/389/EEC                Council decision on a monitoring mechanism of community CO<sub>2</sub> and other greenhouse gas emissions  
  
94/63/EC                Directive on the control of volatile organic compounds (VOCs) emissions resulting from the storage of petrol and its distribution from terminals to petrol stations  
94/66/EC                Directive amending Directive 88/609/EEC on the limitation of emissions of certain pollutants into the air from large combustion plants  
94/67/EC                Directive on the incineration of hazardous waste  
96/61/EC                Directive concerning integrated pollution prevention and control  
96/62/EC                Directive on ambient air quality assessment and management  
98/70/EC                Directive amending 93/12/EC on the sulphur content of liquid fuels  
99/13/EC                Directive on limitation of emissions of volatile organic compounds (VOCs) due to the use of organic solvents in certain activities and installations  
99/30/EC                Directive relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air  
99/32/EC                Directive relating to a reduction in the sulphur content of certain liquid fuels and amending Directive 93/12/EEC

### *Selected decisions*

82/459/EEC                Decision on air pollution monitoring  
88/540/EEC                Decision on Montreal Protocol and the Vienna Convention  
93/389/EEC                Decision on a monitoring mechanism of Community greenhouse gas emissions  
94/69/EEC                Decision on the UN Convention on Climate Change  
94/563/EC                Decision on the quantities of CFCs allowed for essential uses  
95/107/EC                Decision allocating production and import quotas for methyl bromide, import quotas for hydrobromofluorocarbons and consumption quotas for hydrochlorofluorocarbons for the period 1 January to 31 December 1995  
  
95/324/EC                Decision on the quantities of controlled substances allowed for essential uses in the Community in 1996 under Regulation 3093/94 on substances that deplete the ozone layer  
95/555/EC                Decision on companies authorized to use controlled substances for essential uses in 1996  
97/414/EC                Decision on the essential uses of CFCs for 1997  
97/461/EC                Decision on CFCs import quotas for 1997  
98/67/EC                Decision on controlled substances allowed for essential uses in 1998 under Regulation 3093/94 on substances that deplete the ozone layer  
98/27/EC                Decision on import quotas for chlorofluorocarbons (CFCs) for 1998

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|             |                                                                                                                                                                                                                                                                                      |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 98/184/EC   | Decision concerning a questionnaire for Member States' reports on the implementation of Directive 94/67/EC on the incineration of hazardous waste                                                                                                                                    |
| 98/686/EC   | Decision on the Protocol to the 1979 Convention on Transboundary Air Pollution on Further Reduction of Sulphur Emissions                                                                                                                                                             |
| 99/58/EC    | Decision allocating the 1999 import quotas of substances ozone depleting substances                                                                                                                                                                                                  |
| 99/59/EC    | Decision on controlled substances allowed for essential uses in 1999 under Regulation 3093/94 on substances that deplete the ozone layer                                                                                                                                             |
| 99/296/EC   | Decision amending Decision 93/389/EEC for a monitoring mechanism of Community CO <sub>2</sub> and other greenhouse gas emissions                                                                                                                                                     |
| 2000/22/EC  | Decision on the allocation of quantities of controlled substances allowed for essential uses in the Community in 2000 under Council Regulation (EC) No. 3093/94 on substances that deplete the ozone layer                                                                           |
| 2000/379/EC | Decision on import quotas for halogenated chlorofluorocarbons, halons, carbon tetrachloride, 1,1,1-trichloroethane, hydrobromofluorocarbons and methyl bromide and allocating placing on the market quotas for hydrochlorofluorocarbons for the period 1 January to 31 December 2000 |

### ***Selected proposed legislation***

|            |                                                                                                                             |
|------------|-----------------------------------------------------------------------------------------------------------------------------|
| COM(91)268 | Proposal on the Geneva Convention on Long Range Air Pollution                                                               |
| COM(94)109 | Proposal on ambient air quality assessment and management                                                                   |
| COM(97)604 | Proposal to amend 94/67/EC on incineration of hazardous waste                                                               |
| COM(98)398 | Proposal for a regulation on substances which deplete the ozone layer                                                       |
| COM(98)415 | Proposal to amend 88/609/EEC on the limitation of emissions of certain pollutants into the air from large combustion plants |
| COM(98)558 | Proposal on waste incineration                                                                                              |
| COM(98)591 | Proposal for a Directive on limit values for benzene and carbon monoxide in ambient air                                     |
| COM(99)67  | Amended proposal for a Regulation on substances which deplete the ozone layer                                               |

## **UK water legislation**

### ***Selected acts of parliament***

Public Health Act 1936  
 Water Act 1945  
 Rivers (Prevention of Pollution) Act 1951  
 Countryside Act 1968  
 Control of Pollution Act 1974  
 Salmon and Freshwater Fisheries Act 1975  
 Environmental Protection Act 1990  
 Land Drainage Act 1991  
 Water Industry Act 1991  
 Water Resources Act 1991  
 Environment Act 1995  
 Water Industry Act 1999

### ***Selected statutory instruments***

|              |                                                                                           |
|--------------|-------------------------------------------------------------------------------------------|
| SI 1976/958  | Control of Pollution (Discharges to Sewers) Regulations                                   |
| SI 1978/564  | Detergents (Composition) Regulations                                                      |
| SI 1983/1182 | Control of Pollution (Exemption of Certain Discharges from Control) Order                 |
| SI 1984/864  | The Control of Pollution (Consents for Discharges) (Notices) Regulations                  |
| SI 1986/1623 | Control of Pollution (Exemption of Certain Discharges from Control) (Variations) Order    |
| SI 1987/1782 | The Control of Pollution (Exemption of Certain Discharges from Control) (Variation) Order |
| SI 1989/1147 | Water Supply (Water Quality) Regulations                                                  |



- SI 1989/1149 Controlled Water (Lakes and Ponds) Order  
SI 1989/1152 Water and Sewerage (Conservation Access and Recreation) (Code of Practice) Order  
SI 1989/1156 Trade Effluent (Prescribed Processes and Substances) Regulations  
SI 1989/1378 The River (Prevention of Pollution) Act 1951 (Continuation of Bylaws) Order  
SI 1989/1384 Water Supply (Water Quality) (Amendment) Regulations  
SI 1989/1968 Water (Consequential Amendments) Regulations  
SI 1989/2286 Surface Waters (Dangerous Substances) (Classification) Regulations  
SI 1990/1629 Trade Effluents (Prescribed Processes and Substances) (Amendment) Regulations  
SI 1991/324 Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations  
SI 1991/472 Environmental Protection (Prescribed Processes and Substances) Regulations  
SI 1991/507 Environmental Protection (Applications, Appeals and Registers) Regulations  
SI 1991/1597 Bathing Waters (Classification) Regulations  
SI 1991/1837 Water Supply (Water Quality) (Amendment) Regulations  
SI 1991/2790 Private Water Supplies Regulations  
SI 1992/337 Surface Waters (Dangerous Substances) (Classification) Regulations  
SI 1992/339 Trade Effluent (Prescribed Processes and Substances) Regulations  
SI 1994/1057 Surface Waters (River Ecosystem) (Classification) Regulations  
SI 1994/1729 Nitrate Sensitive Areas Regulations  
SI 1994/2841 Urban Waste Water Treatment (England and Wales) Regulations  
SI 1995/1708 The Nitrate Sensitive Areas (Amendment) Regulations  
SI 1995/2095 The Nitrate Sensitive Areas (Amendment) (No. 2) Regulations  
SI 1996/888 Protection of Water Against Agricultural Nitrate Pollution (England and Wales) Regulations  
SI 1996/2044 The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Amendment) Regulations  
SI 1996/2075 Health and Safety at Work etc. Act 1974 (Application to Environmentally Hazardous Substances) Regulations  
  
SI 1996/2971 Control of Pollution (Applications, Appeals and Registers) Regulations  
SI 1996/3001 Surface Waters (Abstraction for Drinking Water) (Classification) Regulations  
SI 1996/3105 The Nitrate Sensitive Areas (Amendment) Regulations  
SI 1997/547 The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) (Amendment) Regulations  
SI 1997/990 The Nitrate Sensitive Areas (Amendment) Regulations  
SI 1997/1331 Surface Waters (Fishlife) (Classification) Regulations  
SI 1997/1332 Surface Waters (Shellfish) (Classification) Regulations  
SI 1997/2560 The Surface Waters (Dangerous Substances) (Classification) Regulations  
SI 1998/314 Food Protection (Emergency Prohibitions) (Oil and Chemical Pollution of Fish) Order 1997 (Revocation) Order  
  
SI 1998/389 Surface Water (Dangerous Substances) (Classification) Regulations  
SI 1998/79 Nitrate Sensitive Areas (Amendments) Regulations  
SI 1998/892 The Mines (Notice of Abandonment) Regulations  
SI 1998/1202 Action Programme for Nitrate Vulnerable Zones (England and Wales) Regulations  
SI 1998/1649 Control of Pollution (Channel Tunnel Rail Link) Regulations  
SI 1998/2138 Nitrate Sensitive Areas (Amendments) (No. 2) Regulations  
SI 1998/2746 The Groundwater Regulations  
SI 1998/3084 Water (Prevention of Pollution) (Code of Practice) Order  
SI 1999/1006 Anti-Pollution Works Regulations  
SI 1999/1148 Water Supply (Water Fittings) Regulations  
SI 1999/1506 Water Supply (Water Fittings) (Amendment) Regulations  
SI 1999/1524 The Water Supply (Water Quality) (Amendment) Regulations  
SI 1999/3440 Water Industry Act 1999 (Commencement No. 2) Order  
SI 1999/3441 Water Industry (Charges) (Vulnerable Groups) Regulations  
SI 1999/3442 Water Industry (Prescribed Conditions) Regulations  
SI 2000/477 Water and Sewerage (Conservation, Access and Recreation) (Code of Practice) Order  
SI 2000/519 Water Industry (Charges) (Vulnerable Groups) (Amendment) Regulations  
SI 2000/1297 The Drinking Water (Undertakings) (England and Wales) Regulations  
SI 2000/1842 Water and Sewerage Undertakers (Inset Appointments) Regulations

## European legislation on water pollution

### *Selected regulations*

No Regulations in this section

### *Selected directives*

|            |                                                                                                                                                                               |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 73/404/EEC | Directive on detergents                                                                                                                                                       |
| 73/405/EEC | Directive on methods of testing the biodegradability of anionic surfactants                                                                                                   |
| 75/439/EEC | Directive on waste oils                                                                                                                                                       |
| 75/440/EEC | Directive on surface water quality                                                                                                                                            |
| 76/160/EEC | Directive on bathing water quality                                                                                                                                            |
| 76/464/EEC | Directive on the discharge of dangerous substances (Framework Directive)                                                                                                      |
| 77/795/EEC | Directive on information on water pollution                                                                                                                                   |
| 78/176/EEC | Directive on titanium dioxide waste                                                                                                                                           |
| 78/659/EEC | Directive on water standards for freshwater fish                                                                                                                              |
| 79/115/EEC | Directive on pilotage of sea vessels                                                                                                                                          |
| 79/869/EEC | Directive concerning the sampling and analysis of drinking water                                                                                                              |
| 79/923/EEC | Directive on water standards for shellfish waters                                                                                                                             |
| 80/68/EEC  | Directive on groundwater                                                                                                                                                      |
| 80/778/EEC | Directive on drinking water quality                                                                                                                                           |
| 82/176/EEC | Directive on mercury (chlor-alkali electrolysis industry)                                                                                                                     |
| 82/242/EEC | Directive on the manufacture and marketing of detergents                                                                                                                      |
| 82/883/EEC | Directive on monitoring of environments concerned by waste from the titanium dioxide industry                                                                                 |
| 83/513/EEC | Directive on cadmium discharges                                                                                                                                               |
| 84/156/EEC | Directive on mercury from non-chlor-alkali electrolysis industry                                                                                                              |
| 84/491/EEC | Directive on hexachlorocyclohexane discharges                                                                                                                                 |
| 86/278/EEC | Directive on sewage sludge used in agriculture                                                                                                                                |
| 86/280/EEC | Directive on limits for certain dangerous substances included in 76/464/EEC                                                                                                   |
| 87/217/EEC | Directive on pollution by asbestos                                                                                                                                            |
| 88/347/EEC | Directive amending Directive 86/280/EEC on certain dangerous substances in 76/464/EEC                                                                                         |
| 90/415/EEC | Directive amending 86/280/EEC on certain dangerous substances included in 76/464/EEC                                                                                          |
| 91/271/EEC | Directive on urban waste water treatment                                                                                                                                      |
| 91/676/EEC | Directive on nitrates from agricultural sources                                                                                                                               |
| 92/112/EEC | Directive on the reduction and eventual elimination of pollution caused from the titanium dioxide industry                                                                    |
| 93/75/EEC  | Directive on minimum requirements of tankers in Community ports                                                                                                               |
| 94/57/EC   | Directive on ship inspection maritime administrations                                                                                                                         |
| 94/58/EC   | Directive on the minimum level of training for seafarers                                                                                                                      |
| 95/21/EC   | Directive concerning the enforcement of international standards for ship safety, pollution prevention and shipboard living and working conditions                             |
| 96/61/EC   | Directive concerning integrated pollution prevention and control                                                                                                              |
| 98/15/EC   | Directive amending 91/271/EEC on urban waste water treatment                                                                                                                  |
| 98/25/EC   | Directive amending 95/21/EC on the enforcement of shipping using community ports, etc.                                                                                        |
| 98/35/EC   | Directive amending 94/58/EC on the minimum level of training for seafarers                                                                                                    |
| 98/42/EC   | Directive amending 95/21/EC on the enforcement of shipping using Community ports                                                                                              |
| 98/55/EC   | Directive amending 93/75/EEC on the minimum requirements for vessels bound for or leaving Community ports, carrying dangerous or polluting goods                              |
| 98/74/EC   | Directive amending 93/75/EEC on the minimum requirements for vessels bound for or leaving Community ports, carrying dangerous or polluting goods                              |
| 98/83/EC   | Directive on the quality of water intended for human consumption                                                                                                              |
| 98/249/EC  | Directive on the conclusion of the convention for the protection of the north east Atlantic                                                                                   |
| 99/97/EC   | Directive amending Directive 95/21/EC concerning the enforcement of international standards for ship safety, pollution prevention and shipboard living and working conditions |



***Selected decisions***

95/308/EC      Decision on the protection and use of transboundary watercourses and international lakes

***Selected proposed legislation***

COM(93)680      Proposal on the ecological quality of water  
COM(94)36      Proposal on bathing water  
COM(97)49      Proposal for a Directive establishing a framework for Community action in the field of water policy  
COM(97)416      Proposal for a Directive amending Directive 95/21/EC on ship safety and pollution prevention  
COM(97)585      Amended proposal for a Directive on the quality of bathing water  
COM(98)76      Amended proposal for a Directive establishing a framework for action on water policy  
COM(98)769      Proposal setting up a Community framework for co-operation with regard to accidental marine pollution

***Selected other legislation***

79/114/EEC      Recommendation on minimum requirements for tankers  
OJ: C162/1/78      Resolution on hydrocarbons at sea  
98/480/EC      Recommendation on good environmental practice for household laundry detergents

**UK legislation on land pollution*****Selected acts***

Environmental Protection Act 1990  
Environment Act 1995

***Selected statutory instruments***

SI 1980/1709      Control of Pollution (Special Waste) Regulations 1980  
SI 1988/1199      Town and Country Planning, England and Wales – The Town and Country Planning (Assessment of Environmental Effects)  
SI 1990/1629      Water, England and Wales – The Trade Effluents (Prescribed Processes and Substances)(Amendment) Regulations 1990  
SI 1990/1187      Water, England and Wales – Agriculture – The Nitrate Sensitive Areas (Designation) (Amendment) Order 1990  
SI 1994/2286      Agriculture – Common Agricultural Policy – The Organic Products (Amendment) Regulations 1994  
SI 1996/972      Environmental Protection – The Special Waste Regulations 1996  
SI 1997/2778      Northern Ireland – The Waste and Contaminated Land (Northern Ireland) Order 1997  
SI 1999/2977      Health and Safety – The Asbestos (Prohibitions)(Amendment)(No. 2) Regulations 1999  
SI 2000/1973      Environmental Protection, England and Wales – The Pollution Prevention and Control (England and Wales) Regulations 2000  
SI 2000/179      European Communities – Town and Country Planning – The Planning (Control of Major – Accident Hazards)(Scotland) Regulations 2000

## Health and Safety Executive publications

### *Selected Codes of Practice*

|        |                                                                                                                                                                                                             |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| COP 2  | Control of lead at work. Approved Code of Practice                                                                                                                                                          |
| COP 6  | Plastic containers with nominal capacities up to 5 litres for petroleum spirit. Requirements for testing and marking or labelling                                                                           |
| COP 14 | Road tanker testing: Examination, testing and certification of the carrying tanks of road tankers and of tank containers used for the conveyance of dangerous substances by road                            |
| COP 20 | Standards of training in safe gas installations. Approved Code of Practice                                                                                                                                  |
| COP 23 | Approved Code of Practice COP 23–Part 3: Exposure to radon. The Ionizing Radiations Regulations 1985 (Superseded by L 121: 2000)                                                                            |
| COP 41 | Control of substances hazardous to health in the production of pottery. The Control of Substances Hazardous to Health Regulations 1988. The Control of Lead at Work Regulations 1980 (superseded by COP 60) |

## HSE guidance notes

### *Agriculture*

|        |                                                                                          |
|--------|------------------------------------------------------------------------------------------|
| AIS 2  | Zoonoses in Agriculture. Preventing the spread of disease to livestock handlers          |
| AIS 3  | Controlling Grain Dust on Farms                                                          |
| AIS 9  | Preventing Access to Effluent Storage and Similar Areas on Farms                         |
| AIS 16 | Guidance on Storing Pesticides for Farmers and other Professional Users                  |
| AIS 31 | Safe Use of Rodenticides on Farms and Holdings                                           |
| AS 5   | Farmer's Lung                                                                            |
| AS 25  | Training in the Use of Pesticides                                                        |
| AS 26  | Protective Clothing for Use with Pesticides                                              |
| AS 27  | Agricultural pesticides                                                                  |
| AS 28  | COSHH in Agriculture. Control of Substances Hazardous to Health Regulations 1988 (COSHH) |
| AS 29  | Sheep Dipping                                                                            |
| AS 30  | COSHH in Forestry                                                                        |
| AS 31  | Veterinary Medicines – Safe Use by Farmers and Other Animal Handlers                     |

### *Best practicable means*

|        |                                                                            |
|--------|----------------------------------------------------------------------------|
| BPM 1  | Best practicable means: general principles and practice                    |
| BPM 2  | Mineral works (sand driers and coolers)                                    |
| BPM 3  | Petroleum works (PVC polymer plants)                                       |
| BPM 4  | Hydrofluoric acid works (HF manufacture)                                   |
| BPM 5  | Hydrochloric acid works                                                    |
| BPM 6  | Mineral works (sintered aggregates)                                        |
| BPM 7  | Metal recovery works                                                       |
| BPM 8  | Mineral works (plaster)                                                    |
| BPM 9  | Aluminium (secondary) works                                                |
| BPM 10 | Amines works                                                               |
| BPM 11 | Chemical incineration works                                                |
| BPM 12 | Iron works and steel works. Electric arc furnaces and associated processes |
| BPM 13 | Mineral works (roadstone plants)                                           |
| BPM 14 | Cement production works                                                    |
| BPM 15 | Mineral works (expansion of perlite)                                       |
| BPM 16 | Lead works                                                                 |
| BPM 17 | Sulphuric acid (Class II) works. Sulphuric acid manufacture                |
| BPM 18 | Chlorine works                                                             |

- BPM 20 Iron works and steel works. Basic oxygen steel plants  
BPM 21 Iron works and steel works. Blast furnaces  
BPM 22 Iron work and steel works. Machine scarfing  
BPM 23 Iron works and steel works. Ore preparation

### *Chemical*

- CS 1 Industrial use of flammable gas detectors  
CS 2 Storage of highly flammable liquids  
CS 3 Storage and use of sodium perchlorate and other similar strong oxidants  
CS 4 Keeping of LPG in cylinders and similar containers  
CS 5 Storage and use of LPG at fixed installations  
CS 6 Storage and use of LPG on construction sites  
CS 7 Odorization of bulk oxygen supplies in shipyards  
CS 8 Small scale storage and display of LPG at retail premises  
CS 9 Bulk storage and use of liquid carbon dioxide: hazards and precautions  
CS 10 Fumigation using methyl phosphine  
CS 11 Storage and use of LPG at metered estates  
CS 12 Fumigation using methyl bromide  
CS 15 The cleaning and gas freeing of tanks containing flammable residues  
CS 16 Chlorine vaporizers  
CS 18 Storage and handling of ammonium nitrate  
CS 19 Storage of approved pesticides: guidance for farmers and other professional users  
CS 20 Sulphuric acid use in agriculture  
CS 21 Storage and handling of organic peroxides  
CS 22 Fumigation  
CS 23 Disposal of waste explosives  
CS 24 The interpretation and use of flashpoint information

### *Environmental hygiene*

- EH 1 Cadmium: health and safety precautions  
EH 2 Chromium and its inorganic compounds: health and safety precautions  
EH 4 Aniline: health and safety precautions  
EH 6 Chromic acid concentrations in air (superseded by MDHS 52/3 (1998))  
EH 7 Petroleum based adhesives in building operations  
EH 8 Arsenic: toxic hazards and precautions  
EH 9 Spraying of highly flammable liquids  
EH 10 Asbestos: exposure limits and measurement of airborne dust concentrations  
EH 11 Arsine: health and safety precautions  
EH 12 Stibine: health and safety precautions  
EH 13 Beryllium: health and safety precautions  
EH 16 Isocyanates: toxic hazards and precautionary measures  
EH 17 Mercury and its inorganic divalent compounds  
EH 19 Antimony and its compounds: health hazards and safety precautions  
EH 20 Phosphine: health and safety precautions  
EH 21 Carbon dust: health and safety precautions  
EH 22 Ventilation of the workplace  
EH 23 Anthrax: health hazards  
EH 24 Dust and accidents in maltheuses  
EH 25 Cotton dust sampling  
EH 26 Occupational skin diseases: health and safety precautions  
EH 27 Acrylonitrile: personal protective equipment  
EH 28 Control of lead: air sampling techniques and strategies  
EH 29 Control of lead: outside workers  
EH 31 Control of exposure to polyvinyl chloride dust  
EH 33 Atmospheric pollution in car parks

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- EH 34 Benzidine-based dyes: health and safety precautions  
 EH 35 Probable asbestos dust concentrations at construction processes. Revised 1989 (superseded by EH 71)  
 EH 36 Cement (superseded by EH 71)  
 EH 37 Work with asbestos insulating board (superseded by EH 71)  
 EH 38 Ozone: health hazards and precautionary measures  
 EH 40 Occupational exposure limits (annual)  
 EH 41 Respiratory protective equipment for use against asbestos  
 EH 42 Monitoring strategies for toxic substances  
 EH 43 Carbon monoxide  
 EH 44 Dust: general principles of protection  
 EH 45 Carbon disulphide: control of exposure in the viscose industry  
 EH 46 Man-made mineral fibres  
 EH 47 Provision, use and maintenance of hygiene facilities for work with asbestos insulation and coatings  
 EH 49 Nitrosamines in synthetic metal cutting and grinding fluids (withdrawn)  
 EH 50 Training operatives and supervisors for work with asbestos insulation and coatings  
 EH 51 Enclosures provided for work with asbestos insulation, coatings and insulating board  
 EH 52 Removal techniques and associated waste handling for asbestos insulation, coatings and insulating board  
 EH 53 Respiratory protective equipment for use against airborne radioactivity  
 EH 54 Assessment of exposure to fume from welding and allied processes  
 EH 55 The control of exposure to fume from welding, brazing and similar processes  
 EH 56 Biological monitoring for chemical exposures in the workplace  
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 EH 60 Nickel and its inorganic compounds: health hazards and precautionary measures  
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 EH 64 Summary criteria for occupational exposure limits 1996 (with updates/changes 1997, 1998, 1999)  
 EH 65/1 Trimethylbenzenes: criteria document for an OEL  
 EH 65/2 Pulverized fuel ash: criteria document for an OEL  
 EH 65/3 N,N-dimethylacetamide: criteria document for an OEL  
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 EH 65/5 4,4'-methylene dianiline: criteria document for an OEL  
 EH 65/6 Epichlorohydrin: criteria document for an OEL  
 EH 65/7 Chlorodifluoromethane: criteria document for an OEL  
 EH 65/8 Cumene: criteria document for an OEL  
 EH 65/9 1,4-dichlorobenzene: criteria document for an OEL  
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 EH 65/15 1,1,1,2-Tetrafluoroethane (HFC 134a): criteria document for an OEL  
 EH 65/16 Methyl methacrylate: criteria document for an OEL  
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 EH 65/18 Propranolol: criteria document for an OEL  
 EH 65/19 Mercury and its inorganic divalent compounds: criteria document for an OEL  
 EH 65/20 Ortho-toluidine: criteria document for an OEL  
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 EH 65/22 Softwood dust: criteria document for an OEL  
 EH 65/23 Antimony and its compounds: criteria document for an OEL  
 EH 65/24 Platinum metal and soluble platinum salts: criteria document for an OEL  
 EH 65/25 Iodomethane: criteria document for an OEL  
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| EH 65/30 | Review of fibre toxicology                                                         |
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| EH 67    | Grain dust in maltings (maximum exposure limits)                                   |
| EH 68    | Cobalt: health and safety precautions                                              |
| EH 69    | How to handle PCBs without harming yourself or the environment                     |
| EH 70    | The control of fire-water run-off from CIMAH sites to prevent environmental damage |
| EH 71    | Working with asbestos cement and asbestos insulating board                         |
| EH 72/1  | Phenylhydrazine: risk assessment document                                          |
| EH 72/2  | Dimethylaminoethanol: risk assessment document                                     |
| EH 72/3  | Bromoethane: risk assessment document                                              |
| EH 72/4  | 3-Chloropropene: risk assessment document                                          |
| EH 72/5  | Alpha-chlorotoluene: risk assessment document                                      |
| EH 72/6  | 2-Furaldehyde: risk assessment document                                            |
| EH 72/7  | 1,2-Diaminoethane (ethylenediamine (EDA)): risk assessment document                |
| EH 72/8  | Aniline: risk assessment document                                                  |
| EH 72/9  | Barium sulphate: risk assessment document                                          |
| EH 72/10 | N-Methyl-2-pyrrolidone: risk assessment document                                   |
| EH 72/11 | Flour dust: risk assessment document                                               |
| EH 73    | Arsenic and its compounds: health hazards and precautionary measures               |
| EH 74/1  | Dichloromethane: exposure assessment document                                      |
| EH 74/2  | Respirable crystalline silica: exposure assessment document                        |
| EH 74/3  | Dermal exposure to non-agricultural pesticides: exposure assessment document       |
| EH 75/1  | Medium density fibreboard (MDF)                                                    |

### ***General***

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| GS 3  | Fire risk in the storage and industrial use of cellular plastics                               |
| GS 4  | Safety in pressure testing (withdrawn, superseded by 1998 edition)                             |
| GS 5  | Entry into confined spaces                                                                     |
| GS 12 | Effluent storage on farms                                                                      |
| GS 16 | Gaseous fire extinguishing systems: precautions for toxic and asphyxiating hazards (withdrawn) |
| GS 19 | General fire precautions aboard ships being fitted out or under repair                         |
| GS 20 | Fire precautions in pressurized workings                                                       |
| GS 26 | Access to road tankers                                                                         |
| GS 40 | The loading and unloading of bulk flammable liquids and gases at harbours and inland waterways |
| GS 43 | Lithium batteries                                                                              |
| GS 46 | <i>In-situ</i> timber treatment using timber preservatives                                     |

### ***Health and safety***

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| HSE 4  | Employers' Liability (Compulsory Insurance) Act 1969. A short guide (superseded by HSE 36: 1998)                                      |
| HSE 5  | The Employment Medical Advisory Service and you                                                                                       |
| HSE 8  | Fires and Explosions due to the misuse of oxygen                                                                                      |
| HSE 11 | Reporting an Injury or a Dangerous Occurrence. (RIDDOR) The Reporting of Injuries, Disease and Dangerous Occurrences Regulations 1985 |
| HSE 17 | Reporting a Case of Disease. (RIDDOR) The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985                  |
| HSE 23 | Health and safety legislation and trainees (a guide for employers)                                                                    |
| HSE 25 | The Health and Safety Executive and you                                                                                               |
| HSE 26 | The Health and Safety Executive working with employers                                                                                |
| HSE 31 | RIDDOR explained – Reporting of Injuries, Diseases and Dangerous Occurrences Regulations                                              |
| HSE 33 | RIDDOR 95 – Offshore                                                                                                                  |
| HSE 36 | Employers' Liability (Compulsory Insurance) Act 1969 – A guide for employees and their representatives (supersedes HSE 4: 1990)       |

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- HS(G)1 Safe use and storage of flexible polyurethane foam in industry  
 HS(G)3 Highly flammable materials on construction sites  
 HS(G)4 Highly flammable liquids in the paint industry  
 HS(G)5 Hot work: welding and cutting on plant containing flammable materials  
 HS(G)7 Container terminals: safe working practices  
 HS(G)10 Cloakroom accommodation and washing facilities  
 HS(G)11 Flame arresters and explosion reliefs  
 HS(G)13 Electrical testing: safety in chemical testing  
 HS(G)14 Opening processes: cotton and allied fibres  
 HS(G)16 Evaporating and other ovens  
 HS(G)20 Guidelines for occupational health services  
 HS(G)21 Safety in the cotton and allied fibres industry: cardroom processes  
 HS(G)22 Electrical apparatus for use in potentially explosive atmospheres  
 HS(G)25 The Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH): further guidance on emergency plans  
 HS(G)26 Transport of dangerous substances in tank containers  
 HS(G)27 Substances for use at work: the provision of information. Revised 1989 (superseded by L 62)  
 HS(G)28 Safety advice for bulk chlorine installations  
 HS(G)30 Storage of anhydrous ammonia under pressure in the United Kingdom  
 HS(G)34 Storage of LPG at fixed installations  
 HS(G)36 Disposal of explosives waste and the decontamination of explosives plant  
 HS(G)37 An introduction to local exhaust ventilation  
 HS(G)39 Compressed air safety  
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 HS(G)41 Petrol filling stations: construction and operation  
 HS(G)49 The examination and testing of portable radiation instruments for external radiations  
 HS(G)50 The storage of flammable liquids in fixed tanks (up to 10 000 m<sup>3</sup> total capacity)  
 HS(G)51 The storage of flammable liquids in containers  
 HS(G)52 The storage of flammable liquids in fixed tanks (exceeding 10 000 m<sup>3</sup> total capacity)  
 HS(G)53 Respiratory protective equipment. A practical guide for users  
 HSG 54 Maintenance, examination and testing of local exhaust ventilation  
 HS(G)61 Health surveillance at work  
 HS(G)62 Health and safety in tyre and exhaust fitting premises  
 HS(G)63 Radiation protection offsite for emergency services in the event of a nuclear accident  
 HS(G)64 Assessment of fire hazards from solid materials and the precautions required for their safe storage and use  
 HSG65 Successful health and safety management  
 HS(G)66 Protection of workers and the general public during development of contaminated land  
 HS(G)70 The control of legionellosis including legionnaires' disease  
 HS(G)71 Storage of packaged dangerous substances  
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 HS(G)72 Control of respirable silica dust in heavy clay and refractory processes  
 HS(G)73 Control of respirable crystalline silica in quarries  
 HS(G)74 Control of silica dust in foundries  
 HS(G)77 COSHH and peripatetic workers (withdrawn)  
 HSG 78 Dangerous goods in cargo transport units – packing and carriage for transport by sea  
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 HS(G)122 New and expectant mothers at work: a guide for employees

- HS(G)123 Working together on firework displays – a guide to safety for firework display organizers and operators
- HS(G)124 Giving your own firework display – how to run and fire it safely
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- HS(G)126 CHIP 2 for everyone
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- HS(G)140 The safe use and handling of flammable liquids
- HS(G)143 Designing and operating safe chemical reaction processes
- HS(G)146 Dispensing petrol – assessing and controlling the risk of fire and explosion at sites where petrol is stored and dispensed as a fuel
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- HS(G)160 The carriage of dangerous goods explained – Part 1: Guidance for consignors of dangerous goods by road and rail (classification, packaging, labelling and provision of information)
- HS(G)161 The carriage of dangerous goods explained – Part 2: Guidance for road vehicle operators and others involved in the carriage of dangerous goods by road
- HS(G)162 The carriage of dangerous goods explained – Part 4: Guidance for operators, drivers and others involved in the carriage of explosives by road
- HS(G)163 The carriage of dangerous goods explained – Part 3: Guidance for rail operators and others involved in the carriage of dangerous goods by rail
- HS(G)164 The carriage of dangerous goods explained – Part 5: Guidance for consignors, rail operators and others involved in the packaging, labelling and carriage of radioactive material by rail
- HS(G)166 Formula for health and safety – guidance for small and medium-sized firms in the chemical industry
- HS(G)167 Biological monitoring in the workplace – a guide to its practical application to chemical exposure
- HS(G)168 Fire safety in construction work: guidance for clients, designers and those managing and carrying out construction work involving significant risks
- HS(G)173 Monitoring strategies for toxic substances
- HSG 174 Anthrax – safe working and the prevention of infection
- HS(G)176 The storage of flammable liquids in tanks
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- HSG 187 Control of diesel engine exhaust emissions in the workplace
- HSG 188 Health risks management – a guide to working with solvents
- HSG 189/1 Controlled asbestos stripping techniques for work requiring a licence
- HSG 189/2 Working with asbestos cement
- HSG 190 Preparing safety reports – Control of Major Accident Hazards Regulations 1999
- HSG 191 Emergency planning for major accidents – Control of Major Accident Hazards Regulations 1999
- HSG 193 Datasheets: COSHH essentials – easy steps to control chemicals
- HSG 202 General ventilation in the workplace. Guidance for employers
- HSG204 Health and safety in arc welding
- HS(G)248 Solder fume and you

### *Health and safety regulations*

- HS(R)1 Packaging and labelling of dangerous substances. Regulations and guidance notes
- HS(R)6 A guide to the HSW Act
- HS(R)12 A guide to the Health and Safety (Dangerous Pathogens) Regulations 1981
- HS(R)13 A guide to the Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981



- HS(R)14 A guide to the Notification of New Substances Regulations. Revised 1988 (obsolete – withdrawn)  
 HS(R)15 Administrative guidance on the European Community ‘Explosive Atmospheres’ Directives (76/117/EEC AND 79/196/EEC) and related Directives  
 HS(R)16 A guide to the Notification of Installations Handling Hazardous Substances Regulations 1982  
 HS(R)17 A guide to the Classification and Labelling of Explosives Regulations 1983  
 HS(R)21 A guide to the Control of Industrial Major Accident Hazards Regulations 1984  
 HS(R)22 A guide to the Classification, Packaging and Labelling of Dangerous Substances Regulations 1984  
 HS(R)23 A guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985  
 HS(R)27 A guide to the Dangerous Substances in Harbour Areas Regulations 1987  
 HS(R)29 Notification and marking of sites. The Dangerous Substances (Notification and Marking of Sites) Regulations 1990  
 HS(R)30 A guide to the Pressure Systems and Transportable Gas Containers Regulations 1989

### *Industrial groups*

- IND(G)3L(Rev) First-aid needs in your workplace: your questions answered. Revised 1994  
 IND(G)4(P) General guidance for inclusion in first-aid boxes  
 IND(G)24L The Gas Regulations: for everybody’s safety  
 IND(G)35L Hot work on tanks and drums  
 IND(G)39L(Rev) Permits-to-work and you. (An introduction for workers in the petroleum industry). Revised 1991  
 IND(G)54L Asbestos: does your company work with asbestos  
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 IND(G)56P Flammable liquids on construction sites  
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 IND(G)62L Protecting your health at work (good health is good business). Revised 4/1993  
 IND(G)64L Introducing assessment. (A simplified guide for employers). Control of Substances Hazardous to Health Regulations 1988 (COSHH)  
 IND(G)65L Introducing COSHH. A brief guide for all employers to the new requirements for controlling hazardous substances in the workplace introduced in the Control of Substances Hazardous to Health Regulations 1988 (COSHH)  
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 IND(G)72L Health hazards to painters  
 IND(G)74L Need advice on occupational Health? A practical guide for employers  
 IND(G)76L Safe systems of work  
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 IND(G)79L Gas appliances – Get them checked – Keep them safe  
 IND(G)82L Your health and reactive dyes  
 IND(G)84L Leptospirosis – are you at risk?  
 IND(G)86(L) Contained use of genetically modified organisms  
 IND(G)91(rev2) Drug misuse at work – A guide for employers  
 IND(G)92L Dangerous substances on site: notification and warning signs  
 IND(G)93L Solvents and you  
 IND(G)95L Save your breath: respiratory sensitizers. (A guide for employers)  
 IND(G)96L Are you involved in the transport of dangerous substances by road (replaced by IND(G)234L)  
 IND(G)97L COSHH and Section 6 of the Health and Safety at Work Act  
 IND(G)98L Permit-to-work systems. (Chemical manufacturing)  
 IND(G)100L An important notice to all gas fitters  
 IND(G)101L AIDS: HIV infection and diving?  
 IND(G)104L Petrol filling stations: control and safety guidance for employees  
 IND(G)107(L) Asbestos and you – Asbestos dust kills – Are you at risk? (superseded by IND(G)289)  
 IND(G)111L Chemical manufacturing: personal protective equipment  
 IND(G)112L Chemical manufacturing: controlling contractors  
 IND(G)114L Are you complying with COSHH?  
 IND(G)115L New explosives controls – Do they affect you? (The Control of Explosives Regulations 1991)  
 IND(G)116L What your doctor needs to know  
 IND(G)123L Radon in the workplace



- INDG 136 COSHH: a brief guide to the regulations  
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IND(G)181(L) The complete idiot's guide to CHIP 2  
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IND(G)233(L) Preventing dermatitis at work – advice for employers and employees  
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IND(G)246L Prepared for . . . emergency  
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IND(G)249L Controlling health risks from rosin (colophony) based solder fluxes  
IND(G)250L How HSE assesses offshore safety cases  
IND(G)251 WASP – Quality assurance for chemical analysis  
IND(G)252(L) Solvents and you – Working with solvents – Are you at risk? (revised 1997)  
IND(G)253L Controlling legionella in nursing and residential care homes  
IND(G)254 Chemical reaction hazards and the risk of thermal runaway  
IND(G)255 Asbestos dust kills – keep your mask on – guidance for employees on wearing respiratory protective equipment for work with asbestos (superseded by 1999 version)  
IND(G)257 Pesticides – Use them safely  
IND(G)258 Safe work in confined spaces (supersedes CS 15 'Confined spaces')  
IND(G)259 An introduction to health and safety  
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| IND(G)288       | Selection of suitable respiratory protective equipment for work with asbestos     |
| IND(G)289       | Working with asbestos in buildings – Asbestos the hidden killer! Are you at risk? |
| INDG 297        | Safety in gas welding, cutting and similar processes                              |
| INDG 300        | Skin cancer caused by oil (replaces MS(B)5)                                       |
| INDG 304        | Understanding health surveillance at work – An introduction for employers         |
| INDG 305 (rev1) | Lead and you – A guide to working safely with lead                                |
| INDG 307        | Hydrofluoric acid poisoning – recommendations on first aid procedures             |
| INDG 308        | The safe use of gas cylinders                                                     |
| INDG 311        | Beryllium and you – working with beryllium – Are you at risk?                     |

### *Legal series*

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| L 5  | General COSHH ACOP (Control of Substances Hazardous to Health) and Carcinogens ACOP (Control of Carcinogenic Substances) and Biological Agents ACOP (Control of Biological Agents) Approved Code of Practice                                                                        |
| L 7  | Approved Code of Practice – Part 4: Dose limitation – Restriction of exposure. Additional guidance on Regulation 6 of the Ionizing Radiations Regulations 1985 (superseded by L 121: 2000)                                                                                          |
| L 8  | The Prevention or Control of Legionellosis (including Legionnaires' Disease) Approved Code of Practice                                                                                                                                                                              |
| L 9  | Safe use of pesticides for non-agricultural purposes – Control of Substances Hazardous to Health Regulations 1994 Approved Code of Practice                                                                                                                                         |
| L 10 | A guide to the Control of Explosives Regulations 1991                                                                                                                                                                                                                               |
| L 11 | A guide to the Asbestos (Licensing) Regulations 1983                                                                                                                                                                                                                                |
| L 13 | A guide to the Packaging of Explosives for Carriage Regulations 1991                                                                                                                                                                                                                |
| L 21 | Management of health and safety at work. Management of Health and Safety at Work Regulations 1999. Approved Code of Practice                                                                                                                                                        |
| L 22 | Safe use of work equipment. Provision and Use of Work Equipment Regulations 1998. Approved Code of Practice and Guidance (revised)                                                                                                                                                  |
| L 24 | Workplace health, safety and welfare. Workplace (Health, Safety and Welfare Regulations) 1992. Approved Code of Practice and Guidance                                                                                                                                               |
| L 25 | Personal protective equipment at work – Guidance on Regulations                                                                                                                                                                                                                     |
| L 27 | The control of asbestos at work. Control of Asbestos at Work Regulations 1987 – Approved Code of Practice 3rd edition (revised)                                                                                                                                                     |
| L 28 | Work with asbestos insulation, asbestos coating and asbestos insulating board – Control of Asbestos at Work Regulations 1987 – Approved Code of Practice 3rd edition (revised)                                                                                                      |
| L 29 | A guide to the Genetically Modified Organisms (Contained Use) Regulations 1992, as amended in 1996                                                                                                                                                                                  |
| L 30 | A guide to Offshore Installations (Safety Case) Regulations 1992                                                                                                                                                                                                                    |
| L 37 | Safety data sheets for substances and preparations dangerous for supply (superseded by L 62)                                                                                                                                                                                        |
| L 45 | Explosives at coal and other safety-lamp mines                                                                                                                                                                                                                                      |
| L 53 | Approved methods for the classification and packaging of dangerous goods for carriage by road and rail – Carriage of Dangerous Goods by Road and Rail (Classification, Packaging and Labelling) Regulations 1994 (superseded by L 88 1996)                                          |
| L 55 | Preventing asthma at work: how to control respiratory sensitizers                                                                                                                                                                                                                   |
| L 56 | Safety in the installation and use of gas systems and appliances – Gas Safety (Installations and Use) Regulations 1998 Approved Code of Practice and guidance                                                                                                                       |
| L 57 | Approved carriage list – Information approved for the classification, packaging and labelling of dangerous goods for carriage by road and rail – Carriage of Dangerous Goods by Road and Rail (Classification, Packaging and Labelling) Regulations 1994 (superseded by L 88: 1996) |
| L 58 | Approved Code of Practice – The Protection of persons against ionizing radiation arising from any work activity – The Ionizing Radiations Regulations 1985 (superseded by L 121: 2000)                                                                                              |
| L 60 | Approved Code of Practice – Control of Substances Hazardous to Health in the Production of Pottery (formerly COP 41) (reprinted with amendments 1998)                                                                                                                               |
| L 62 | Safety datasheets for substances and preparations dangerous for supply                                                                                                                                                                                                              |
| L 65 | Approved Code of Practice and guidance – Prevention of Fire and Explosion, and Emergency Response on Offshore Installations (Prevention of Fire and Explosion and Emergency Response) Regulations 1995                                                                              |
| L 66 | A guide to the Placing on the Market and Supervision of Transfers of Explosives Regulations 1993 (POMSTER)                                                                                                                                                                          |
| L 67 | Control of vinyl chloride at work                                                                                                                                                                                                                                                   |
| L 70 | A guide to the Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995                                                                                                                                                                           |

- L73 RIDDOR explained – A guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995
- L 74 First aid at work. Approved Code of Practice and guidance
- L 80 A guide to the Gas Safety (Management) Regulations 1996
- L 82 A guide to the Pipelines Safety Regulations 1996
- L 83 A guide to the Installation, Verification and Miscellaneous Aspects of Amendments by the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996 to the Offshore Installations (Safety Case) Regulations 1992
- L 84 A guide to the well aspects of amendments of the Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996
- L 85 A guide to the integrity, workplace environment and miscellaneous aspects of the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996
- L 86 Control of substances hazardous to health in fumigation operations
- L 88 Approved requirements and test methods for the classification and packaging of dangerous goods for carriage
- L 89 Approved vehicle requirements
- L 90 Approved carriage list
- L 91 Suitability of vehicles and containers and limits on quantities for the carriage of explosives by road
- L 92 Approved requirements for the construction of vehicles intended for the carriage of explosives by road
- L 93 Approved tank requirements: the provisions for bottom loading and vapour recovery systems of mobile containers carrying petrol
- L 94 Approved requirements for the packaging, labelling and carriage of radioactive material by rails
- L 95 A guide to the Health and Safety (Consultation with Employees) Regulations 1996
- L 96 A guide to the Work in Compressed Air Regulations 1996
- L 100 Approved guide to the classification and labelling of substances and preparations dangerous for supply
- L 101 Safe working in confined spaces – Approved Code of Practice, Regulations and guidance – Confined Spaces Regulations 1997
- L 110 A guide to the Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989 – guidance on Regulations
- L 111 A guide to the Control of Major Accident Hazards Regulations 1999 – COMAH – guidance on Regulations
- L 118 Health and safety at quarries
- L 121 Work with ionizing radiation. Ionizing Radiations Regulations 1999. Approved Code of Practice and guidance
- L 122 Safety of pressure systems. Pressure Systems Safety Regulations 2000. Approved Code of Practice

### ***Dangerous substances (general) – HSE***

Major hazard aspects of the transport of dangerous substances 1991

Recommendations for training users of non-agricultural pesticides

Health surveillance under COSHH. *Guidance for employers*

Anaesthetic agents. *Controlling exposure under COSHH*

Risk assessments of notified new substances

Asthmagens. Critical assessments of the evidence for agents implicated in occupational asthma 1997.

The technical basis for COSHH essentials. *Easy steps to control chemicals*

### ***Methods for determination of hazardous substances***

- MDHS 1 Acrylonitrile in air (charcoal adsorption tubes)
- MDHS 2 Acrylonitrile in air (porous polymer adsorption tubes)
- MDHS 3 Generation of test atmospheres of organic vapours by the syringe injection technique
- MDHS 4 Generation of test atmospheres of organic vapours by the permeation tube method
- MDHS 5 On-site validation of sampling methods
- MDHS 6/3 Lead and inorganic compounds of lead in air (atomic absorption spectrometry)
- MDHS 7 Lead and inorganic compounds of lead in air (X-ray fluorescence spectrometry)
- MDHS 8 Lead and inorganic compounds of lead in air (colorimetric field method)
- MDHS 9 Tetra alkyl lead compounds in air (personal monitoring)
- MDHS 10/2 Cadmium and inorganic compounds in air (atomic absorption spectrometry)

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|           |                                                                                                        |
|-----------|--------------------------------------------------------------------------------------------------------|
| MDHS 11   | Cadmium and inorganic compounds of cadmium in air (X-ray fluorescence spectroscopy)                    |
| MDHS 12/2 | Chromium and inorganic compounds of chromium in air (atomic absorption spectrometry)                   |
| MDHS 13   | Chromium and inorganic compounds of chromium in air (X-ray fluorescence spectroscopy)                  |
| MDHS 14/3 | General methods for sampling and gravimetric analysis of respirable and inhalable dust                 |
| MDHS 15   | Carbon disulphide in air                                                                               |
| MDHS 16   | Mercury vapour in air (hopcalite adsorbent tubes)                                                      |
| MDHS 17   | Benzene in air (charcoal adsorbent tubes)                                                              |
| MDHS 18   | Tetra alkyl lead compounds in air (continuous on-site monitoring)                                      |
| MDHS 19   | Formaldehyde in air                                                                                    |
| MDHS 20   | Styrene in air                                                                                         |
| MDHS 21   | Glycol ether and glycol ether acetate vapours in air (charcoal adsorbent tubes)                        |
| MDHS 22   | Benzene in air (porous polymer adsorbent tubes)                                                        |
| MDHS 23   | Glycol ether and glycol ether acetate vapours in air (Tenax adsorbent tubes)                           |
| MDHS 24   | Vinyl chloride in air                                                                                  |
| MDHS 25/3 | Organic isocyanates in air                                                                             |
| MDHS 26   | Ethylene oxide in air                                                                                  |
| MDHS 27   | Protocol for assessing the performance of a diffusive sampler                                          |
| MDHS 28   | Chlorinated hydrocarbon solvent vapours in air                                                         |
| MDHS 29/2 | Beryllium and inorganic compounds of beryllium in air                                                  |
| MDHS 30/2 | Cobalt and cobalt compounds in air – Laboratory method using flame atomic absorption spectrometry      |
| MDHS 31   | Styrene in air                                                                                         |
| MDHS 32   | Dioctyl phthalates in air                                                                              |
| MDHS 33/2 | Sorbent tube standards                                                                                 |
| MDHS 34   | Arsine in air                                                                                          |
| MDHS 35/2 | Hydrogen fluoride and inorganic fluorides in air                                                       |
| MDHS 36   | Toluene in air                                                                                         |
| MDHS 37   | Quartz in respirable airborne dusts (direct method)                                                    |
| MDHS 38   | Quartz in respirable airborne dusts (KBr disc technique)                                               |
| MDHS 39/4 | Asbestos fibres in air                                                                                 |
| MDHS 40   | Toluene in air                                                                                         |
| MDHS 41/2 | Arsenic and inorganic compounds of arsenic (except arsine) in air                                      |
| MDHS 42/2 | Nickel and inorganic compounds of nickel in air (except nickel carbonyl)                               |
| MDHS 43   | Styrene in air (porous polymer diffusive samplers, thermal desorption and gas chromatography)          |
| MDHS 44   | Styrene in air (charcoal diffusive samplers, solvent desorption and gas chromatography)                |
| MDHS 45   | Ethylene dibromide in air                                                                              |
| MDHS 46/2 | Platinum metal and soluble platinum compounds in air                                                   |
| MDHS 47/2 | Determination of rubber process dust and rubber fume (measured as cyclohexane-soluble material) in air |
| MDHS 48   | Newspaper print rooms: measurement of total particulates and cyclohexane soluble material in air       |
| MDHS 49   | Aromatic isocyanates in air                                                                            |
| MDHS 50   | Benzene in air (porous polymer diffusion samplers, thermal desorption and gas chromatography)          |
| MDHS 51   | Quartz in respirable airborne dusts (X-ray diffraction)                                                |
| MDHS 52/3 | Hexavalent chromium in chromium plating mists (supersedes EH 6 and MDHS 52/2: 1990)                    |
| MDHS 53   | 1,3-Butadiene in air                                                                                   |
| MDHS 54   | Protocol for assessing the performance of a pumped sampler for gases and vapours                       |
| MDHS 55   | Acrylonitrile in air                                                                                   |
| MDHS 56/2 | Hydrogen cyanide in air                                                                                |
| MDHS 57   | Acrylamide in air                                                                                      |
| MDHS 58   | Mercury vapour in air (diffusive samplers)                                                             |
| MDHS 59   | Man-made mineral fibre                                                                                 |
| MDHS 60   | Mixed hydrocarbons (C3 to C10) in air                                                                  |
| MDHS 61   | Total hexavalent chromium compounds in air                                                             |
| MDHS 62   | Aromatic carboxylic acid anhydrides in air                                                             |
| MDHS 63   | 1,3-Butadiene in air (molecular sieve diffusive samplers, thermal desorption and gas chromatography)   |
| MDHS 64   | Toluene in air (charcoal diffusive samplers, solvent desorption and gas chromatography)                |
| MDHS 66   | Mixed hydrocarbons (C5 to C10) in air                                                                  |
| MDHS 67   | Total (and speciated) chromium in chromium plating mists                                               |
| MDHS 68   | Coal tar pitch volatiles: measurement of particulates and cyclohexane soluble material in air          |
| MDHS 69   | Toluene in air                                                                                         |

|         |                                                                                                             |
|---------|-------------------------------------------------------------------------------------------------------------|
| MDHS 70 | General methods for sampling airborne gases and vapours                                                     |
| MDHS 71 | Analytical quality in workplace air monitoring                                                              |
| MDHS 72 | Volatile organic compounds in air                                                                           |
| MDHS 73 | Measurement of air change rates in factories and offices                                                    |
| MDHS 74 | <i>n</i> -Hexane in air                                                                                     |
| MDHS 75 | Aromatic amines in air and on surfaces                                                                      |
| MDHS 76 | Cristobalite in respirable airborne dust                                                                    |
| MDHS 77 | Asbestos in bulk materials – Sampling and identification by polarized light microscopy (PLM)                |
| MDHS 78 | Formaldehyde in air                                                                                         |
| MDHS 79 | Peroxodisulphates in air                                                                                    |
| MDHS 80 | Volatile organic compounds in air                                                                           |
| MDHS 81 | Dustiness of powders and materials                                                                          |
| MDHS 82 | The dust lamp – A simple tool for observing the presence of airborne particles                              |
| MDHS 83 | Resin acids in rosin (colophony) solder flux fume                                                           |
| MDHS 84 | Measurement of oil mist from mineral oil-based metalworking fluids                                          |
| MDHS 85 | Triglycidyl isocyanurate (and coating powders containing triglycidyl isocyanurate) in air                   |
| MDHS 86 | Hydrazine in air                                                                                            |
| MDHS 87 | Fibres in air                                                                                               |
| MDHS 88 | Volatile organic compounds in air                                                                           |
| MDHS 89 | Dimethyl sulphate and diethyl sulphate in air                                                               |
| MDHS 91 | Metals and metalloids in workplace air by X-ray fluorescence spectrometry                                   |
| MDHS 92 | Azodicarbonamide in air                                                                                     |
| MDHS 93 | Glutaraldehyde in air                                                                                       |
| MDHS 94 | Pesticides in air and/or on surfaces                                                                        |
| MDHS 95 | Measurement of personal exposure of metalworking machine operators to airborne water-mix metalworking fluid |
| MDHS 96 | Volatile organic compounds in air                                                                           |

## ***Medical***

|             |                                                                                               |
|-------------|-----------------------------------------------------------------------------------------------|
| MS 3        | Skin tests in dermatitis and occupational chest disease                                       |
| MS 4        | Organic dust surveys (obsolete – withdrawn)                                                   |
| MA 5        | Health and Safety Executive's Medical Division: agency nurses and occupational health nursing |
| MA 6        | Occupational health aspects of pregnancy                                                      |
| MS 9        | Byssinosis (obsolete)                                                                         |
| MS 12       | Mercury: medical guidance notes                                                               |
| MS 13       | Asbestos: medical guidance notes                                                              |
| MS 15       | Welding                                                                                       |
| MS 17 (rev) | Medical aspects of work-related exposures to organophosphates                                 |
| MS 21       | Precautions for the safe handling of cytotoxic drugs                                          |
| MS 22       | The medical monitoring of workers exposed to platinum salts                                   |
| MS 23       | Health aspects of job placement and rehabilitation – Advice to employers                      |
| MS 24       | Medical aspects of occupational skin disease                                                  |
| MS 25       | Medical aspects of occupational asthma                                                        |
| MSA 1       | Lead and you – A guide to working safely with lead                                            |
| MS(A)7      | Cadmium and you – working with cadmium – Are you at risk?                                     |
| MS(A)8      | Arsenic and you. Arsenic is poisonous – Are you at risk?                                      |
| MS(A)9      | What you should know about cyanide poisoning. (A guide for employers)                         |
| MS(A)11     | Working with MbOCA                                                                            |
| MS(A)12     | Acid and you (withdrawn)                                                                      |
| MSA 13      | Benzene and you – Working with benzene – Are you at risk? (revision 1)                        |
| MS(A)14     | Nickel and you – Working with nickel – Are you at risk?                                       |
| MS(A)15     | Silica dust and you                                                                           |
| MS(A)16     | Chromium and you                                                                              |
| MS(A)17     | Cobalt and you – Working with cobalt – Are you at risk?                                       |
| MS(A)18     | Beryllium and you – Working with beryllium – Are you at risk?                                 |
| MS(A)19     | PCBs and you – Do you know how to work safely with PCBs?                                      |

|         |                                                                      |
|---------|----------------------------------------------------------------------|
| MSA 21  | MbOCA and you – Do you use MbOCA?                                    |
| MS(B)16 | Save your breath: occupational lung disease. (A guide for employers) |
| MS(B)3  | Anthrax (information card)                                           |
| MS(B)4  | Skin cancer caused by pitch and tar                                  |
| MS(B)5  | Skin cancer caused by oil (replaced by INDG 300)                     |
| MS(B)7  | Poisoning by pesticides. First aid                                   |
| MS(B)9  | Save your skin: occupational contact dermatitis                      |

### ***Offshore***

|        |                                                                                  |
|--------|----------------------------------------------------------------------------------|
| OTI442 | A fibre optic sensor for flexible pipeline and riser integrity monitoring        |
| OTI521 | Improving inherent safety                                                        |
| OTI586 | Representative range of blast and fire scenarios                                 |
| OTI587 | The prediction of single and two-phase release rates                             |
| OTI588 | Legislation, codes of practice and certification requirements                    |
| OTI591 | Gas/vapour build up on offshore structures                                       |
| OTI592 | Confined vented explosions                                                       |
| OTI593 | Explosions in highly congested volumes                                           |
| OTI594 | The prediction of the pressure loading on structures resulting from an explosion |
| OTI595 | Possible ways of mitigating explosions on offshore structures                    |
| OTI596 | Oil and gas fires                                                                |
| OTI597 | Behaviour of oil and gas fires in the presence of confinement and obstacles      |
| OTI606 | Passive fire protection                                                          |
| OTI607 | Availability and properties of passive and active fire protection systems        |
| OTI634 | Jet-fire resistance test of passive fire protection materials                    |

### ***Plant and machinery***

|        |                                                                                                                           |
|--------|---------------------------------------------------------------------------------------------------------------------------|
| PM 75  | Glass reinforced plastic vessels and tanks: advice to users                                                               |
| PM 77  | Fitness of equipment used for medical exposure to ionising radiation                                                      |
| PM 81  | Safe management of ammonia refrigeration systems – food and other workplaces                                              |
| PM 82  | The selection, installation and maintenance of electrical equipment for use in and around buildings containing explosives |
| PML 52 | 7 steps to successful substitution of hazardous substances                                                                |

### ***Plastics processing***

|        |                                                                          |
|--------|--------------------------------------------------------------------------|
| PPIS 1 | Fire and explosion risks from pentane in expandable polystyrene (EPS)    |
| PPIS 2 | Plastics recycling                                                       |
| PPS 4  | Safety at injection moulding machines                                    |
| PPS 5  | Safety at blow moulding machines                                         |
| PPS 6  | Safety at thermoforming machines                                         |
| PPS 9  | Plastics processing sheet No. 9: safety at compression moulding machines |
| PPS 10 | Safety at granulators                                                    |

### ***Research papers***

|       |                                                                   |
|-------|-------------------------------------------------------------------|
| RP 28 | Grain dust: some of its effects on health                         |
| RP 30 | Occupational health advice as part of primary health care nursing |
| RP 31 | The fracture behaviour of polyethylene – A literature review      |
| RP 32 | First aid retention of knowledge survey                           |

### ***Cautionary notices***

|          |                                                                                     |
|----------|-------------------------------------------------------------------------------------|
| SHW 2125 | Warning: Danger of explosion in oil fuel storage tanks fitted with immersed heaters |
|----------|-------------------------------------------------------------------------------------|



- SHW 396 Effects of lemon and orange peeling on the skin  
SHW 397 (rev) Effects of mineral oil on the skin  
SHW 987 Celluloid fire dangers. Warning to workers. (Leaflet)

### ***Specialist inspector reports***

- SIR 3 Control of exhaust fumes from vehicles working in enclosed spaces  
SIR 5 Avoiding water hammer in steam systems  
SIR 9 The fire and explosion hazards of hydraulic accumulators  
SIR 10 Sick building syndrome  
SIR 14 Dust control at woodworking processes  
SIR 16 Low-volume high-velocity extraction systems  
SIR 19 Fire and explosion hazards associated with the storage and handling of hydrogen peroxide  
SIR 20 Spraying and the design of spray booths  
SIR 21 Assessment of the toxicity of major hazard substances  
SIR 22 Reliability of airflow measurements in assessing ventilation systems' performance  
SIR 25 Cobalt – a review of properties, use and levels of exposure  
SIR 26 A review of respirable crystalline silica – Exposure and control  
SIR 27 Some occupational hygiene aspects of man-made mineral fibres and new technology fibres  
SIR 31 Safe handling requirements during explosive, propellant and pyrotechnic manufacture  
SIR 37 Simplified calculations of blast induced injuries and damage  
SIR 41 Laboratory work with chemical carcinogens and oncogenes  
SIR 42 Rosin (colophony): a review  
SIR 48 Occupational hygiene aspects on the safe use and selection of refrigerant fluids  
SIR 51 Remediation of contaminated land, occupational hygiene aspects on the safe selection and use of new soil clean-up techniques  
SIR 56 A study of occupational dermatitis in further education training hairdressing establishments in Scotland

### ***Textiles***

- TIS 1 Dyes and chemicals in textile finishing: an introduction  
TIS 2 Non-dyestuff chemicals: safe handling in textile finishing  
TIS 3 Dyestuffs: safe handling in textile finishing  
TIS 4 Hazards from dyes and chemicals in textile finishing: a brief guide for employees  
TIS 5 Reactive dyes: safe handling in textile finishing

### ***Toxicity reviews***

- TR 1 Styrene  
TR 2 Formaldehyde  
TR 3 Carbon disulphide  
TR 4 Benzene  
TR 5 Pentachlorophenol  
TR 6 Trichloroethylene  
TR 7 Cadmium and its compounds  
TR 8 Trimellitic anhydride (TMA) 4,4'-Methylenebis (2-chloroaniline) (MbOCA) *N*-Nitrosodiethanolamine (NDELA)  
TR 9 1,1,1-Trichloroethane  
TR 10 Glycol ethers  
TR 11 1,3-Butadiene and related compounds  
TR 12 Dichloromethane  
TR 13 Vinylidene chloride  
TR 14 Phthalate esters  
TR 15 Carcinogenic hazard of wood dusts. Carcinogenicity of crystalline silica  
TR 16 Inorganic arsenic compounds

|       |                                                                                                                                              |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------|
| TR 17 | Tetrachloroethylene                                                                                                                          |
| TR 18 | <i>n</i> -Hexane                                                                                                                             |
| TR 19 | The toxicity of nickel and its inorganic compounds                                                                                           |
| TR 20 | Toluene                                                                                                                                      |
| TR 21 | The toxicity of chromium and inorganic chromium compounds                                                                                    |
| TR 22 | Bis (chloromethyl) ether                                                                                                                     |
| TR 23 | Part 1: Carbon tetrachloride. Part 2: Chloroform                                                                                             |
| TR 24 | Part 1: Ammonia. Part 2: 1-Chloro-2,3-epoxypropane (epichlorohydrin). Part 3: Carcinogenicity of cadmium and its compounds                   |
| TR 25 | Cyclohexane, cumene, para-dichlorobenzene (p-DCB), chlorodifluoromethane (CFC22)                                                             |
| TR 26 | Xylenes                                                                                                                                      |
| TR 27 | Triglycidyl isocyanurate, beryllium and beryllium compounds                                                                                  |
| TR 28 | Cancer epidemiology in coal tar pitch volatile-associated industries                                                                         |
| TR 29 | Cobalt and cobalt compounds                                                                                                                  |
| TR 30 | Phosphorus compounds (phosphoric acid, phosphorous pentoxide, phosphorous oxychloride, phosphorous pentachloride, phosphorous pentasulphide) |
| TR 31 | Dimethylcarbamoyl chloride                                                                                                                   |

## Woodworking

|        |                                                                                        |
|--------|----------------------------------------------------------------------------------------|
| WIS 1  | Wood dust: hazards and precautions                                                     |
| WIS 6  | COSHH and the woodworking industries                                                   |
| WIS 10 | Glue spreading machines                                                                |
| WIS 11 | Hardwood dust survey                                                                   |
| WIS 12 | Assessment and control of wood dust: use of the dust lamp                              |
| WIS 14 | Selection of respiratory protective equipment suitable for use with wood dust          |
| WIS 19 | Health risks during furniture stripping using dichloromethane (DCM)                    |
| WIS 23 | LEV – general principles of system design                                              |
| WIS 24 | LEV – dust capture at sawing machines                                                  |
| WIS 25 | LEV – dust capture at fixed belt sanding machines                                      |
| WIS 26 | LEV – dust capture at fixed drum and disc sanding machines                             |
| WIS 29 | Occupational hygiene and health surveillance at industrial timber pre-treatment plants |
| WIS 30 | Toxic woods                                                                            |
| WIS 32 | Safe collection of woodwaste: prevention of fire and explosion                         |
| WIS 33 | Health surveillance and wood dust                                                      |
| WIS 34 | Health and safety priorities for the woodworking industry                              |

## Miscellaneous

### *Supplements to carriage of dangerous goods explained (HSG series)*

|         |                                                                                                                                                                                                               |
|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SUPP 05 | Supplement to Carriage of Dangerous Goods (HSG 160) Explained – Part 1 – Guidance for Consignors of Dangerous Goods by Road and Rail. Classification, Packaging, Labelling and Provision of Information       |
| SUPP 06 | Supplement to Carriage of Dangerous Goods Explained (HSG 161) – Part 2 – Guidance for Vehicle Operators and Others Involved in the Carriage of Dangerous Goods by Road                                        |
| SUPP 07 | Supplement to Carriage of Dangerous Goods Explained (HSG 163 which updates L 51) – Part 3 – Guidance for Rail Operators and Others Involved in the Carriage of Dangerous Goods by Rail                        |
| SUPP 08 | Supplement to Carriage of Dangerous Goods Explained (HSG 164) – Part 5 – Guidance for Consignors, Rail Operators and Others Involved in the Packaging, Labelling and Carriage of Radioactive Material by Rail |



## **Publications by the Environment Agency relating to chemicals**

### ***Prevention of pollution series***

|       |                                                                   |
|-------|-------------------------------------------------------------------|
| PPG1  | General guide to the prevention of pollution of controlled waters |
| PPG2  | Above ground oil storage tanks                                    |
| PPG3  | The use and design of oil separators                              |
| PPG4  | Disposal of sewage where no mains drainage is available           |
| PPG5  | Works in, near or liable to affect water courses                  |
| PPG6  | Working at demolition and construction sites                      |
| PPG7  | Fuelling stations: construction and operation                     |
| PPG8  | Safe storage and disposal of used oils                            |
| PPG9  | Pesticides                                                        |
| PPG10 | Highway depots                                                    |
| PPG11 | Industrial sites                                                  |
| PPG12 | Sheep dip                                                         |
| PPG13 | The use of high pressure water and steam cleaners                 |
| PPG14 | Boats and marinas                                                 |
| PPG15 | Retail premises                                                   |
| PPG16 | Schools and other educational establishments                      |
| PPG17 | Dairies and other milk handling operations                        |
| PPG18 | Managing fire water and major spillages                           |
| PPG19 | Garages and vehicle service centres                               |
| PPG20 | Dewatering underground ducts and chambers                         |
| PPG22 | Dealing with spillages on highways                                |

Masonry bunds for oil storage tanks  
Concrete bunds for oil storage tanks  
Chemical pollution and how to avoid it  
River pollution and how to avoid it  
Pollution from your home and how to avoid it  
Solvent pollution and how to avoid it  
Silt pollution and how to avoid it  
Farm pollution and how to avoid it  
Making the right connection  
Follow the oil care code  
Oil care at home  
Oil care at work  
Oil care on your boat  
Oil tank sticker  
Domestic oil tank sticker  
Control of Pollution (Slurry, Silage and Agricultural Fuel Oil) Regulations 1991

### ***Waste management***

Duty of care – waste and your duty of care  
The registration of waste carriers – who needs to register, how to apply and what it costs  
New packaging regulations – how do they affect you?  
Producer responsibility obligations 1997 – guidance on evidence of compliance and accreditation of re-processors  
A new waste management licensing system – what it means – how it affects you

### ***Special waste regulations***

How they affect you  
Classification of special waste

Use of the consignment note  
Obtaining and sending consignment notes

## Selected British Standards

- BS 341: PART 1 AMD 1 Transportable gas container valves. Part 1: Industrial valves for working pressures up to and including 300 bar (AMD 7641) dated 15 May 1993: Partially replaced BS 341. Part 1: 1962 and BS 341: Part 2: 1963
- BS 476: PART 12 Fire tests on building materials and structures. Part 12: Method of test for ignitability of products by direct flame impingement. Replaced BS 476: Part 5: 1979
- BS 476: PART 20 AMD 1 Fire tests on building materials and structures. Part 20: Method for determination of the fire resistance of elements of construction (general principles) (AMD 6487) dated 30 April 1990. Replaced BS 476: Part 8: 1972
- BS 476: PART 21 Fire tests on building materials and structures. Part 21: Methods for determination of the fire resistance of loadbearing elements of construction. Replaced BS 476: Part 8: 1972
- BS 476: PART 22 Fire tests on building materials and structures. Part 22: Methods for determination of the fire resistance of non-loadbearing elements of construction. Replaced BS 476: Part 8: 1972
- BS 476: PART 23 AMD 1 Fire tests on building materials and structures. Part 23: Methods for determination of the contribution of components to the fire resistance of a structure (AMD 9458) dated January 1998. Replaced BS 476: Part 8: 1972
- BS 499: PART 2 (Withdrawn) 1980 AMD 2 Welding terms and symbols. Part 2: Specification for symbols for welding (AMD 7439) dated 15 November 1992. Withdrawn, superseded by BS EN 24063: 1992 and BS EN 22553: 1995
- BS 1542 (Withdrawn) 1982 Equipment for eye, face and neck protection against non-ionizing radiation arising during welding and similar operations. Withdrawn, superseded by BS EN 175:1997
- BS 1547 (Withdrawn) 1959 Flameproof industrial clothing (materials and design) . . . Withdrawn, superseded by BS EN 469: 1995 and BS EN 531: 1995
- BS 1870: PART 1 AMD 1 Safety footwear. Part 1: Safety footwear other than all-rubber and all-plastics moulded types (AMD 6273) dated 28 February 1990. Superseded by BS EN 345: 1993 and BS EN 346: 1993
- BS 1870: PART 2 AMD 4 Safety footwear. Part 2: Lined rubber safety boots (AMD 4741) dated 31 January 1985. Superseded by BS EN 345: 1993
- BS 1870: PART 3 AMD 1 Safety footwear. Part 3: Polyvinyl chloride moulded safety footwear (AMD 4742) dated 31 January 1985. Superseded by BS EN 345: 1993
- BS 2091 (Withdrawn) 1969 AMD 2 Respirators for protection against harmful dust, gases and schedule agricultural chemicals. Withdrawn, superseded by BS EN 136,140,141,143,371, and 372
- BS 2092 (Withdrawn) 1987 AMD 1 Eye-protectors for industrial and non-industrial uses (AMD 7061) dated 15 October 1993. Withdrawn, partially superseded by BS EN 167 and 168: 1995
- BS 2653 (Withdrawn) 1955 AMD 3 Protective clothing for welders. Withdrawn, superseded by BS EN 470-1: 1995
- BS 2782 (Withdrawn) 1993 Methods of testing plastics. Method 140B: Determination of the burning behaviour of flexible vertical specimens in contact with a small-flame ignition source. Withdrawn, superseded by BS EN ISO 9773: 1999
- BS 2782 (Withdrawn) 1993 Methods of testing plastics. Method 140C: Determination of the combustibility of specimens using a 125 mm flame source. Withdrawn, superseded by BS EN 60695-11-20: 1999
- BS 2782 Methods of testing plastics. Method 140D: Flammability of a test piece 550 mm × 35 mm of thin polyvinyl chloride sheeting (laboratory method). Supersedes BS 2782: Part 1: Method 140D: 1980
- BS 3042 (Withdrawn) 1992 Test probes to verify protection by enclosures. Withdrawn, superseded by BS EN 61032: 1998
- BS 3156 Methods for the analysis of fuel gases
- BS 3202: PART 1 Laboratory furniture and fittings. Supersedes BS 3202: 1959
- BS 3841: PART 1 Determination of smoke emission from manufactured solid fuels for domestic use. Part 1: General method for determination of smoke emission rate. Superseded BS 3841: 1972
- BS 3841: PART 2 Determination of smoke emission from manufactured solid fuels for domestic use. Part 2: Methods for measuring the smoke emission rate. Superseded BS 3841: 1972

- BS 3951 (Withdrawn) 1989 AMD 2 Freight containers
- BS 4078: PART 1 AMD 1 Powder actuated fixing systems. Part 1: Code of practice for safe use (AMD 9899) dated April 1998. Superseded BS 4078: 1966
- BS 4422: PART 6 Glossary of terms associated with fire. Part 6: Evacuation and means of escape. Superseded BS 4422: Part 3: 1972
- BS 4434 AMD 1 Specification for safety and environmental aspects in the design, construction and installation of refrigerating appliances and systems (AMD 9383) dated 15 March 1997. Supersedes BS 4434: 1989
- BS 4555 (Withdrawn) 1970 High efficiency dust respirators. Withdrawn, superseded by BS EN 136: 1990, and BS EN 143: 1991
- BS 4558 (Withdrawn) 1970 Positive pressure, powered dust respirators. Withdrawn, superseded by BS EN 136: 1990, BS EN 143: 1991 and BS EN 147
- BS 4680 Clothes lockers. Superseded BS 4680: 1971
- BS 4771 (Withdrawn) 1971 Positive pressure, powered dust hoods and blouses. Withdrawn, superseded by BS EN 143: 1991 and BS EN 146: 1992
- BS 4972 AMD 4 Women's protective footwear (AMD 6374) dated 31 July 1991. Superseded by BS EN 346: 1993
- BS 5045: PART 3 (Withdrawn) 1984 AMD 4 Transportable gas containers. Part 3: Seamless aluminium alloy gas containers above 0.5 litre water capacity and up to 300 bar charged pressure at 15 °C (AMD 6320) dated 31 January 1991. Withdrawn, superseded by BS EN 1975: 2000 and BS 5045-8: 2000
- BS 5111: PART 1 (Withdrawn) 1974 AMD 1 Laboratory methods of test for determination of smoke generation characteristics of cellular plastics and cellular rubber materials. Part 1: Method for testing a 25 mm cube test specimen of low density material (up to 130 kg/metres cubed) to continuous flaming conditions (AMD 7688) dated 15 July 1993. Withdrawn, superseded by BS ISO 5659-2: 1994
- BS 5045: PART 3 (Withdrawn) 1984 AMD 4 Transportable gas container. Superseded by BS EN 1975: 2000 and BS 5045-8: 2000
- BS 5111 (Withdrawn) 1974 AMD 1 Laboratory methods of test for determination of smoke generation characteristics of cellular plastics and cellular rubber materials. Superseded by BS ISO 5659-2: 1994
- BS 5240: PART 1 (Withdrawn) 1987 Industrial safety helmets. Part 1: Construction and performance. Withdrawn, superseded by BS EN 397: 1995
- BS 5266-7 Lighting applications. Emergency lighting. Also BS EN 1838: 1999 partially superseded BS 5266-1: 1988
- BS 5274 (Withdrawn) 1985 Fire hose reels (water) for fixed installations. Withdrawn, superseded by BS EN 671-1: 1995
- BS 5345: PART 1 (Withdrawn) 1989 AMD 3 Code of practice for selection, installation and maintenance of electrical apparatus for use in potentially explosive atmospheres (other than mining applications or explosives processing and manufacture). Part 1: General recommendations (AMD 7871) dated 15 September 1993. Withdrawn, superseded by BS EN 60079-14: 1997
- BS 5345: PART 6 (Withdrawn) 1978 AMD 1 Code of practice for selection, installation and maintenance of electrical apparatus for use in potentially explosive atmospheres (other than mining applications or explosives processing and manufacture). Part 6: Recommendations for type of protection. Increased safety (AMD 5557) dated 30 November 1989. Withdrawn, superseded by BS EN 60079
- BS 5423 (Withdrawn) 1987 AMD 3 Portable fire extinguishers (AMD 8585) dated 15 December 1995. Withdrawn, superseded by BS 7863: 1996, BS 7867: 1997 and BS EN 3-1 to 6
- BS 5445: PART 1 (Withdrawn) 1977 Components of automatic fire detection systems. Part 1: Introduction. Withdrawn, superseded by BS EN 54-1: 1996
- BS 5445: PART 5 AMD 1 Components of automatic fire detection systems. Part 5: Heat sensitive detectors; point detectors containing a static element (AMD 5762) dated 31 August 1988. Superseded BS 3116: Part 1: 1970
- BS 5499: PART 1 AMD 1 Fire safety signs, notices and graphic symbols. Part 1: Fire safety signs (AMD 7444) dated 15 January 1993. Superseded BS 2560: 1968
- BS 5499: PART 2 Fire safety signs, notices and graphic symbols. Part 2: Self-luminous fire safety signs. Superseded BS 4218: 1978
- BS 5499: PART 3 Fire safety signs, notices and graphic symbols. Part 3: Internally illuminated fire safety signs. Superseded BS 2560: 1978

- BS 5588: PART 1 AMD 1 Fire precautions in the design, construction and use of buildings. Part 1: Code of practice for residential buildings (AMD 7840) dated 15 September 1993. Superseded BS 5502: Sec 1.3: 1986 and BS 5588: Section 1.1: 1984 and CP 3: Chapter IV: Part 1
- BS 5588: PART 11 AMD 2 Fire precautions in the design, construction and use of buildings. Part 11: Code of practice for shops, offices, industrial storage and other similar buildings (AMD 10213) dated January 1999. Supersedes BS 5588: Part 2: 1985 and BS 5588: Part 3: 1983
- BS 5588: PART 2 (Withdrawn) 1985 AMD 3 Fire precautions in the design, construction and use of buildings. Part 2: Code of practice for shops (AMD 6478) dated 31 August 1990. Withdrawn, superseded by BS 5588: Part 11: 1997
- BS 5588: PART 3 (Withdrawn) 1983 AMD 3 Fire precautions in the design, construction and use of buildings. Part 3: Code of practice for office buildings (AMD 6160) dated 31 October 1989. Withdrawn, superseded by BS 5588: Part 11: 1997
- BS 5588: PART 8 Fire precautions in the design, construction and use of buildings. Part 8: Code of practice for means of escape for disabled people. Supersedes BS 5588-8: 1988, which is withdrawn
- BS 5726: PART 4 AMD 1 Microbiological safety cabinets. Part 4: Recommendations for selection, use and maintenance (AMD 7784) dated 15 June 1993. Supersedes BS 5726: 1979
- BS 6467 AMD 1 Electrical apparatus with protection by enclosure for use in the presence of combustible dusts. Superseded by BS EN 50281-1-1 and 1-2 but remains current
- BS 6535: PART 3 (Withdrawn) 1989 Fire extinguishing media.. Part 3: Powder. Withdrawn, superseded by BS EN 615: 1995
- BS 6535 (Withdrawn) 1990 Fire extinguishing media. Part 2: Halons. Section 2.1: Halon 1211 and halon 1301. Withdrawn, now BS EN 27201-1: 1994
- BS 6535: SEC 2.2 (Withdrawn) 1989 Fire extinguishing media. Part 2: Halons. Section 2.2: Code of practice for safe handling and transfer procedures. Withdrawn, superseded by BS EN 27201-2: 1994
- BS 6575 (Withdrawn) 1985 AMD 1 Fire blankets (AMD 8938) dated 15 December 1995. Withdrawn, superseded by BS 7944: 1999
- BS 6941 Electrical apparatus for explosive atmospheres with type of protection N. Superseded by BS EN 50021: 1999 but remains current
- BS 6967 (Withdrawn) 1988 Glossary of terms for personal eye-protection. Withdrawn, superseded by BS EN 165: 1996
- BS 7355 (Withdrawn) 1990 Full face masks for respiratory protective devices. Withdrawn, superseded by BS EN 136: 1998
- BS 7356 (Withdrawn) 1990 AMD 1 Half masks and quarter masks for respiratory protective devices (AMD 7113) dated 15 November 1992. Withdrawn, superseded by BS EN 140: 1999
- BS 7535 Guide to the use of electrical apparatus complying with BS 5501 or BS 6491 in the presence of combustible dusts
- BS 7750 (Withdrawn) 1994 Environmental management systems. Withdrawn, superseded by BS EN ISO 14001: 1996
- BS 7863 AMD 2 Recommendations for colour coding to indicate the extinguishing media contained in portable fire extinguishers (AMD 9740) dated October 1997. With BS EN 3: Parts 1 to 6, supersedes BS 5423: 1987
- BS 7944 Type 1 heavy duty fire blankets and type 2 heavy duty heat protective blankets. Superseded BS 7944: 1985
- BS EN 2 Classification of fires. Superseded BS 4547: 1972
- BS EN 3-1 Portable fire extinguishers. Description, duration of operation, Class A and B fire test. With BS EN 3-2 to 6 and BS 7863: 1996, Superseded BS 5423: 1987 (still current)
- BS EN 3-2 Portable fire extinguishers. Tightness, dielectric test, tamping test, special provisions. With BS EN 3-1 and 3 to 6 and BS 7863: 1996, superseded BS 5423: 1987 (current)
- BS EN 3-3 Portable fire extinguishers. Construction, resistance to pressure, mechanical tests. With BS EN 3 Parts 1 to 6, BS 7863, superseded BS 5423: 1987 (still current)
- BS EN 3-4 Portable fire extinguishers. Charges, minimum required fire. With BS EN 3-1, 3 and 5 to 6 and BS 7963: 1996, superseded BS 5423: 1987 (current)
- BS EN 3-5 AMD 1 Portable fire extinguishers. Specification and supplementary tests (AMD 9618) dated October 1997. With BS EN 3-1 to 4 and 6 and BS 7863: 1996, superseded BS 5423: 1987 (current)
- BS EN 3-6 AMD 1 Portable fire extinguishers. Provisions for the attestation of conformity of portable fire extinguishers in accordance with EN 3 Parts 1 to 5 (AMD 10494) dated September 1999. With BS EN 3-1 to 5 and BS 7863: 1996, superseded BS 5423: 1987
- BS EN 54-1 Fire detection and fire alarm systems. Introduction, supersedes BS 5445: Part 1: 1977

- BS EN 54-2 Fire detection and fire alarm systems. Control and indicating equipment. With BS EN 54-4: 1997, superseded BS 5839: Part 4: 1998 which remains current
- BS EN 54-4 Fire detection and fire alarm systems. Power supply equipment. With BS EN 54-2: 1997, supersedes BS 5839: Part 4: 1988 which remains current
- BS EN 132 Respiratory protective devices – Definitions of terms and pictograms. Superseded BS 6927: 1988
- BS EN 133 Respiratory protective devices – Classification superseded BS 6928: 1988
- BS EN 135 Respiratory protective devices – List of equivalent terms. Supersedes BS 6930: 1988
- BS EN 136 Respiratory protective devices – Full face masks – Requirements, testing, marking. Supersedes BS EN 136-10: 1992 and BS 7355: 1990
- BS EN 137 AMD 1 Respiratory protective devices: self-contained open-circuit compressed air breathing apparatus (AMD 8167) dated 15 May 1994. Supersedes BS 7004: 1988 and BS 4667: Part 2: 1974
- BS EN 139 AMD 2 Respiratory protective devices – Compressed air line breathing apparatus for use with a full face mask, half mask or a mouthpiece assembly – Requirements, testing, marking (AMD 10774) dated January 2000. With BS EN 138, BS EN 269 and BS EN 270, superseded BS 4667-3: 1974
- BS EN 145 Respiratory protective devices – Self-contained closed-circuit breathing apparatus, compressed oxygen or compressed oxygen–nitrogen type. Requirements, testing, marking. Supersedes BS 7170: 1990 and BS EN 145-2: 1993
- BS EN 149 Filtering half masks to protect against particles. Superseded BS 6016: 1980
- BS EN 161 AMD 2 Automatic shut-off valves for gas burners and gas appliances (AMD 9796) dated January 1998. With BS 7461, superseded BS 5963: 1981
- BS EN 165 Personal eye-protection – Vocabulary. Superseded BS 6967: 1988
- BS EN 166 Personal eye-protection – Specifications. With BS EN 167: 1995 and BS EN 168: 1995. Supersedes BS 2092: 1987
- BS EN 167 Personal eye-protection – Optical test methods. Partially superseded BS 2092: 1987
- BS EN 168 Personal eye-protection – Non-optical test methods. Partially superseded BS 2092: 1987
- BS EN 175 AMD 1 Personal protection – Equipment for eye and face protection during welding and allied processes (AMD 9902) dated January 1998. Supersedes BS 1542: 1982
- BS EN 203-1 AMD 3 Gas heated catering equipment. Safety requirements (AMD 10573) dated December 1999. Supersedes BS 5314
- BS EN 345 (Withdrawn) 1993 Safety footwear for professional use. Withdrawn, now BS EN 345-1: 1993
- BS EN 345-1 Safety footwear for professional use. Specification. Previously known as BS EN 345: 1993
- BS EN 346 (Withdrawn) 1993 Protective footwear for professional use. Withdrawn, now known as BS EN 346-1: 1993
- BS EN 346-1 Protective footwear for professional use. Specification. Previously BS EN 346: 1993, read with BS EN 344-1: 1993
- BS EN 347 (Withdrawn) 1993 Occupational footwear for professional use. Withdrawn, now known as BS EN 347-1: 1993
- BS EN 367 AMD 1 Protective clothing – Protection against heat and fire – Method of determining heat transmission on exposure to flame (AMD 7667) dated 15 May 1993. Supersedes BS 3791: 1970
- BS EN 372 SX gas filters and combined filters against specific named compounds used in respiratory protective equipment. Supersedes BS 2091: 1969
- BS EN 388 Protective gloves against mechanical risks. Supersedes BS 1651: 1986
- BS EN 397 Specification for industrial safety helmets. Supersedes BS 5240: Part 1: 1987
- BS EN 400 Respiratory protective devices for self rescue – Self-contained closed circuit breathing apparatus – Compressed oxygen escape apparatus – Requirements, testing and marking. Supersedes BS 4667: Part 5: 1990
- BS EN 407 Protective gloves against thermal risks (heat and/or fire). Supersedes BS 1651: 1986
- BS EN 420 AMD 1 General requirements for gloves (AMD 8515) dated 15 February 1995. Supersedes BS 1651: 1986
- BS EN 443 Helmets for firefighters. Supersedes BS 3864: 1989
- BS EN 470-1 AMD 2 Protective clothing for use in welding and allied processes. General requirements (AMD 10318) dated February 1999. Supersedes BS 2653: 1955
- BS EN 1596 Specification for dedicated liquefied petroleum gas appliances – Mobile and portable non-domestic forced convection direct fired air heaters. Supersedes BS 4096: 1967



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| BS EN 1751        | Ventilation for buildings – Air terminal devices – Aerodynamic testing of dampers and valves. Superseded BS 6821: 1988                                                                                                                                                              |
| BS EN 1838        | Lighting applications – Emergency lighting. Also BS 5266-7: 1999                                                                                                                                                                                                                    |
| BS EN 1869        | Fire blankets. Partially. Superseded BS 6565: 1985                                                                                                                                                                                                                                  |
| BS EN 25923       | Fire protection – Fire extinguishing media – Carbon dioxide. Previously BS 6535: Part 1: 1990                                                                                                                                                                                       |
| BS EN 27201-1     | Fire protection – Fire extinguishing media – Halogenated hydrocarbons. Halon 1211 and Halon 1301. Previously BS 6535: Section 2.1: 1990                                                                                                                                             |
| BS EN 27201-2     | Fire protection – Fire extinguishing media – Halogenated hydrocarbons. Code of practice for safe handling and transfer procedures. Supersedes BS 6535: Section 2.2: 1989                                                                                                            |
| BS EN 12673       | Water quality – Gas chromatographic determination of some selected chlorophenols in water. Also BS 6068-2.65: 1999                                                                                                                                                                  |
| BS EN 12941       | Respiratory protective devices – Powered filtering devices incorporating a helmet or a hood – Requirements, testing, marking. Superseded BS EN 146: 1992                                                                                                                            |
| BS EN 50014       | AMD 2 Electrical apparatus for potentially explosive atmospheres – General requirements (AMD 10552) dated August 1999. Partially superseded BS EN 50014: 1993 which remains current                                                                                                 |
| BS EN 50014       | AMD 1 Electrical apparatus potentially explosive atmospheres – General requirements (AMD 8132) dated 15 March 1994. Partially superseded by BS EN 50014: 1998 (remains current)                                                                                                     |
| BS EN 50015       | Electrical apparatus for potentially explosive atmospheres – Oil immersion ‘o’. Supersedes BS EN 50015: 1994 which remains current                                                                                                                                                  |
| BS EN 50017       | Electrical apparatus for potentially explosive atmospheres – Powder filling ‘q’. Superseded BS EN 50017: 1994 which remains current                                                                                                                                                 |
| BS EN 50020       | AMD 1 Electrical apparatus for potentially explosive atmospheres – Intrinsic safety ‘i’ (AMD 10040) dated June 1998. Read with BS EN 50014: 1993                                                                                                                                    |
| BS EN 50281-1-1   | AMD 1 Electrical apparatus for use in the presence of combustible dust. Part 1: Electrical apparatus protected by enclosures – Construction and testing (AMD 10764) dated October 1999. Partially superseded BS 6467-1 and 2 which remain current                                   |
| BS EN 50281-1-2   | AMD 1 Electrical apparatus for use in the presence of combustible dust. Part 1: Electrical apparatus protected by enclosures – Selection, installation and maintenance (AMD 10763) dated October 1999. Inc.Cor.1(10856)Part.s/s BS 6467-1: 1985 and BS 6467-2: 1988, remain current |
| BS EN 531         | AMD 1 Protective clothing for workers exposed to heat (AMD 10302) dated January 1999. Partially superseded BS 1547: 1959                                                                                                                                                            |
| BS EN 533         | Protective clothing – Protection against heat and flame – Limited flame spread materials and material assemblies. Superseded BS 6249: Part 1: 1982                                                                                                                                  |
| BS EN 615         | Fire protection – Fire extinguishing media – Specifications for powders (other than class D powders). Superseded BS 6535: Part 3: 1989                                                                                                                                              |
| BS EN 671-1       | Fixed firefighting systems – Hose systems. Hose reels with semi-rigid hose. Supersedes BS 5274: 1985                                                                                                                                                                                |
| BS EN 779         | AMD 1 Particulate air filters for general ventilation – Requirements, testing, marking (AMD 8367) dated 15 November 1994. Superseded BS 6540: Part 1: 1985                                                                                                                          |
| BS EN ISO 6326-3  | Natural gas – Determination of sulfur compounds. Determination of hydrogen sulfide, mercaptan sulfur, and carbonyl sulfide sulfur by potentiometry. Also BS 3156: Subsection 11.4.3: 1994                                                                                           |
| BS EN ISO 6326-5  | Natural gas – Determination of sulfur compounds. Lingener combustion method. Also BS 3156: Subsection 11.4.5: 1994                                                                                                                                                                  |
| BS EN ISO 9000-1  | Quality management and quality assurance standards. Guidelines for selection and use. Previously BS 5750: Section 0.11: 1987                                                                                                                                                        |
| BS EN ISO 9001    | Quality systems – Model for quality assurance in design, development, production, installation and servicing. Previously BS 5750: Part 1: 1987                                                                                                                                      |
| BS EN ISO 9002    | Model for quality assurance in production, installation and servicing. Previously BS 5750: Part 2: 1987                                                                                                                                                                             |
| BS EN ISO 9004-1  | Quality management and quality assurance standards. Guidelines. Previously BS 5750: Section 0.2: 1987                                                                                                                                                                               |
| BS EN ISO 10101-1 | Natural gas – Determination of water by the Karl Fischer method. Also BS 3156 (10053)                                                                                                                                                                                               |
| BS EN ISO 14001   | Environmental management systems – Specification with guidance for use. Superseded BS 7750: 1994 which remains current                                                                                                                                                              |
| BS EN 60079-10    | AMD 1 Electrical apparatus for explosive gas atmospheres. Classification of hazardous areas (AMD 9340) dated 15 November 1996. Superseded BS 5345: Part 2: 1983                                                                                                                     |

- BS EN 60079-14 AMD 1 Electrical apparatus for explosive gas atmospheres. Electrical installations in hazardous areas (other than mines). Corrigendum No. 1 (Corr. 10013) dated April 1998, superseded BS 5345: Part 1: 1989, Parts 2 and 7: 1979, Part 4: 1977, Part 5: 1983, Part 6: 1978 and Part 8: 1980
- BS EN 60309-2 Plugs, socket-outlets and couplers for industrial purposes. Dimensional interchangeability requirements for pin and contact-tube accessories. Superseded BS EN 60309-2: 1998, which remains current
- BS EN 60432-1 AMD 1 Incandescent lamps – Safety specifications. Tungsten filament lamps for domestic and similar general lighting purposes (AMD 9775) dated January 1998. Superseded by BS EN 60432-1: 2000, but remains current
- BS EN 60529 AMD 1 Degrees of protection provided by enclosures (IP code) (AMD 7643) dated 15 July 1993. Superseded BS 5490: 1977
- BS EN 60598-2-22 Luminaires. Part 2: Particular requirements. Particular requirements – Luminaires for emergency lighting. Incorporating Corrigendum No. 1 (AMD 10562) dated December 1999. Inc.Cor1, Superseded BS 4533: Section 102.22: 1990, which remains current
- BS EN 60695-11-20 Fire hazard testing. Part 11: Test flames – 500 W flame test methods. Superseded BS 2782 – 140C: 1993
- BS EN 60695-2-2 AMD 1 Fire hazard testing. Part 2: Test methods. Needle-flame test (AMD 9176) dated 15 November 1996. Previously known as BS 6458: Section 2.2: 1993
- BS EN 60695-4 Fire hazard testing. Terminology concerning fire tests. Superseded BS 6458: Part 1: 1990
- BS EN 60707 Flammability of solid non-metallic materials when exposed to flame sources – List of test methods. Superseded BS 6334: 1983
- BS EN 60721-3-1 Classification of environmental conditions. Part 3: Classification of groups of environmental parameters and their severities. Storage. Superseded BS EN 60721-3-1: 1993
- BS EN 60721-3-2 Classification of environmental conditions. Part 3: Classification of groups of environmental parameters and their severities. Transportation. Superseded BS EN 60721-3-2: 1993
- BS EN 60721-3-3 AMD 1 Classification of environmental conditions. Part 3: Classification of groups of environmental parameters and their severities. Stationary use at weather protected locations (AMD 9514) dated 15 June 1997. Superseded BS EN 60721-3-3: 1993. Previously BS 7527: Section 3.3: 1991
- BS EN 60721-3-4 AMD 1 Classification of environmental conditions. Part 3: Classification of groups of environmental parameters and their severities. Stationary use at non-weather protected locations (AMD 9513) dated 15 June 1997. Previously BS 7527: Section 3.4: 1991
- CP 15/1 Code of Practice 15/1: The safe re-rating of existing BS 5045: Part 1: 1982 Containers to amendment AMD 5145: 1986. Part 1: Permanent gas containers (excluding hydrogen trailer service)
- CP 15/2 Code of Practice 15/2: The safe re-rating of existing BS 5045: Part 1: Cylinders to amendment AMD 5145: 1986. Part 2: Containers for hydrogen trailer service
- DD 180 Guide for the assessment of toxic hazards in fire in buildings and transport. Superseded by BS 7899: Parts 1, 2 and 3 but remains current
- DD 189 (Withdrawn) 1990 Safety of condensing boilers (2nd and 3rd family gases). Withdrawn, superseded by BS EN 677: 1998
- DD 211 (Withdrawn) 1992 Method for detection and enumeration of *Legionella* organisms in water and related materials. Withdrawn, superseded by BS 6068-4.12: 1998

# **Selected UK legislation relevant to environmental protection and occupational health and safety in relation to chemicals**

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The general principles outlined in this work for the identification and control of hazardous chemicals are independent of legislation. However, regulatory obligations forcing compliance with national and/or local requirements should be consulted. Space prevents encyclopaedic coverage but the following brief selection of relevant UK legislation serves to illustrate the scope. It is supplemented by the lists of legislation in the Bibliography.

## **General health and safety**

The minimum standards for health and safety are those outlined in numerous pieces of statutory legislation. These include the:

Factories Act 1961  
Health and Safety at Work etc. Act 1974  
Management of Health and Safety at Work Regulations 1992  
Management of Health and Safety at Work (Amendment) Regulations 1994  
Manual Handling Operations Regulations 1992

All of these contain requirements of relevance to work with hazardous chemicals.

## **Selected legislation relevant to the control of hazardous chemicals**

The following legislation is of direct relevance.

### *Asbestos (Prohibitions) Regulations 1992*

Cover the prohibition of the importation, supply or new use of amphibole asbestos or products containing it. Also prohibit the supply and use of a range of products containing chrysotile asbestos.

### *Carriage of Dangerous Goods by Rail Regulations 1996*

The scope includes carriage of dangerous substances by wagons, large containers, small containers and tanks. Cover the documentation requirements, the mode of transport, the information needs, loading/unloading, security, safety



and emergency requirements with special provisions for explosives. The carriage of temperature-controlled substances is prohibited.

*Carriage of Dangerous Goods by Road Regulations 1996*

Cover the carriage of dangerous goods by road in bulk, in tanks and in containers. The requirements for documentation, information, loading/unloading, and emergencies and parking are included.

*Carriage of Dangerous Goods by Road (Driver Training) Regulations 1996*

Cover the instruction, training and certification of drivers of motor vehicles engaged in the carriage of dangerous goods.

*Carriage of Dangerous Goods (Classifications, Packaging and Labelling) and Use of Transportable Pressure Receptacles Regulations 1996*

Cover the classification, packaging and labelling of dangerous goods. The requirements for design, manufacture, modification, repair, approval, certification and marking of transportable pressure containers are included. The role of 'approved persons' to comply with the regulations is explained.

*Carriage of Explosives by Road Regulations 1996*

Prohibit the carriage of certain explosives. Concerned with the carriage of explosives in vehicles used to carry passengers and carriage in bulk. The suitability of both vehicle and container, vehicle approval, types of vehicles, and quantity limits for loads are regulated. Cover the requirements for information, and safety and security during transit. This includes route of carriage, parking, load integrity, equipment, precautions against fire and explosion, and the requirements in the event of accidents and emergencies.

*Chemicals (Hazard Information and Packaging for Supply) Regulations 1994*

Regulate the classification, provision of safety data sheets, labelling and packaging of substances and preparations dangerous for supply. There are specific exceptions, e.g. medicines, pesticides, wastes, radioactive substances or preparations.

*Confined Spaces Regulations 1997*

Requirements for work in confined spaces, including avoidance of entry if reasonably practicable, provision of a safe system of work and establishment of adequate emergency arrangements.

*Control of Asbestos at Work Regulations 1987 (amended 1992 and 1999)*

Requirements for the control of asbestos exposures at work. Exposure is to be prevented or, if this is not reasonably practicable, reduced to the lowest level reasonably practicable by measures other than the use of respiratory protective equipment.

*Control of Explosives Regulations 1991*

Concerned mainly with the security of explosives and restricted substances. Applicable to the acquisition, keeping, handling and control of explosives, e.g. blasting explosives, detonators, fuses, ammunitions, propellants, pyrotechnics and fireworks.

*Control of Lead at Work Regulations 1980*

Requirements for protecting the health of workers exposed to lead including lead alloys, lead compounds and lead containing substances. A risk assessment is necessary.

Provision of adequate information, instruction and training; control against exposures by measures other than the use of personal protective equipment; provision of adequate washing facilities; prohibition of eating, drinking and smoking in contaminated areas; and health surveillance are covered.

*Control of Major Accident Hazard Regulations 1999*

Regulate the design and operation of defined major hazard installations. All necessary measures are required to prevent and limit the consequences of major accidents. Operators of upper-tier sites must produce a detailed Safety Report; those of lower-tier sites must prepare a Major Accident Prevention Policy.

*Control of Pesticides Regulations 1986*

Prohibit the advertisement, supply, storage and use of pesticides unless they have been approved. 'Pesticides' includes herbicides, fungicides, wood preservatives, plant growth hormones, soil sterilants, bird or animal repellants,

masonry biocides and anti-foul boat paints. Conditions are applied to supply, storage and use. Competence training and certification is required for commercial use in agriculture generally.

*Control of Substances Hazardous to Health Regulations 1999*

Cover the control of substances classified as very toxic, toxic, harmful, corrosive, sensitizing or irritant under the Chemicals (Hazard Information and Packaging for Supply) Regulations 1994 (as amended) and to substances which have MELs or OESs. Also other substances that have chronic or delayed effects and biological agents. Special provisions are included for carcinogens.

*Dangerous Substances in Harbour Areas Regulations 1987*

Requirements for prior notice of arrival of dangerous substances into ports.

*Dangerous Substances (Notification and Marking of Sites) Regulations 1990*

Requirements for notification and appropriate marking of any site containing large quantities of dangerous substances. Principally aimed at the safety of fire officers attending incidents.

*Fire Precaution Act 1971*

Provides for the control of fire safety in all designated occupied premises, by ensuring that adequate general fire precautions are taken and appropriate means of escape and related precautions are present. Specifies the requirements for a fire certificate for various premises.

*Fire Precautions (Workplace) Regulations 1997, as amended*

Apply to all workplaces, unless specifically excepted, and require a fire risk assessment; where necessary, appropriate fire-fighting equipment with detectors and alarms; measures for fire-fighting; emergency routes and exits; maintenance of equipment provided.

*Gas Safety (Installation and Use) Regulations 1994*

Requirements for any employer of, or self-employed, persons to be members of the Council for Registered Gas Installers (CORGI). Individual gas fitters must possess certificates of competence.

*Health and Safety (First-Aid) Regulations 1981*

Requirements for every employer to provide equipment and facilities which are adequate and appropriate in the circumstances for administering first aid to employees. Adequate numbers of suitable persons are needed to administer first aid.

*Health and Safety (Safety Signs and Signals) Regulations 1996*

Cover means of communicating health and safety information in all workplaces. Include illuminated signs, alarms, verbal communication, fire safety signs, marking of pipework, etc.

*Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972*

Cover the storage, handling and use of highly flammable liquids, viz. liquids with a flashpoint  $<32^{\circ}\text{C}$  and which support combustion when tested in the prescribed ways. Also cover the manner of storage and the marking of storage accommodation for LPG, viz. commercial propane, commercial butane and any mixture of the two.

*Ionizing Radiations Regulations 1999*

Cover all work with ionizing radiations, including exposure to naturally occurring radon gas. Special arrangements are required to protect outside workers, e.g. contractors. Specified practices need authorization and the regulatory authority must receive prior notification of specified work. Govern risk assessment, exposure, personal dosimetry, engineering controls, personal protective equipment, contingency plans, management controls, designated areas, control of radioactive substances.

*Notification of New Substances Regulations 1993*

Requirements for the notification of new substances, irrespective of their potential for harm, before they can be placed on the market. Aim to ensure that a chemical placed on the market can be validly marketed in any EU state without duplicating authorization.

*Packaging, Labelling and Carriage of Radioactive Material by Rail Regulations 1996*

Govern the need for documentation, design for special forms of radioactive material, approval, packaging, loading/unloading, and shipment including the requirement for prior inspections. Also cover security measures and procedures in the event of emergencies plus obligations on provision of information, emission evaluation and certification.

*Personal Protective Equipment at Work Regulations 1992*

Cover all aspects of the provision, maintenance and use of personal protective equipment at work and in other circumstances.

*Petroleum Consolidation Act 1928*

Regulates the use, transport or storage of petroleum spirit and – as extended by other legislation – mixtures, e.g. adhesives, thinners or lacquers containing petroleum, and non-petroleum based solvents with a flash point <73°F.

*Provision and Use of Work Equipment Regulations 1998*

Govern the provision and use of all work equipment (i.e. any machinery, appliance, apparatus, tool or installation for use at work) including mobile and lifting equipment. Cover general requirements relating to the selection, inspection and maintenance of equipment, protection against specific risks (e.g. dangerous parts of machinery, high or very low temperature, equipment failure scenarios, discharge of any article or substance from equipment) and the provision of instruction, information and training.

*Radioactive Substance Act 1993*

Governs the keeping and use of radioactive substances and the storage and disposal of radioactive waste.

*Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995*

Requirements for the reporting of certain categories of injury and disease sustained at work, and specific dangerous occurrences or gas incidents, to the enforcing authority.

*Social Security (Industrial Injuries) (Prescribed Diseases) Regulations 1985*

List the diseases prescribed for the payment of disablement benefit, if related to specific occupations. Conditions due to chemical agents, e.g. poisoning by any of a range of chemicals and certain carcinomas, and miscellaneous conditions, e.g. pneumoconiosis, asthma, diffuse mesothelioma, non-infective dermatitis are included.

*Transport of Dangerous Goods (Safety Advisers) Regulations 1999*

Requirements for provision of adequate information, time and other resources to safety advisers to fulfil their functions. These include monitoring compliance with rules relating to transportation of dangerous goods; advising on transportation; implementing emergency procedures; investigating serious accidents, incidents or infringements and implementing measures to avoid a recurrence, etc.

*Workplace (Health, Safety and Welfare Regulations) 1992*

Aim to protect the health and safety of everyone in the workplace and ensure that adequate welfare facilities are provided. Covers e.g. general ventilation, temperature in indoor workplaces, lighting, cleanliness, space requirements, condition of floors and traffic routes, measures against falls/falling objects, washing facilities.

## **Environmental protection legislation**

*Clean Air Act 1993*

Sets out ancillary controls related to air pollution control including regulation of smoke, grit, dust and fume emissions from non-prescribed industrial processes; provision of a lower level of control over some smaller combustion plants not covered by IPC or LAAPC; prohibition of the emission of 'dark smoke' from any chimney or industrial premises.

*Environment Act 1995*

Created the Environment Agency (EA) and the SEA for Scotland. Contains detailed provisions for dealing with a range of environmental issues including air quality; contaminated land; reinforcing the 'polluter pays' principle; water quality, with the EA empowered to require action to prevent water pollution and to require polluters to clean up after any pollution episode.

*Environmental Protection (Duty of Care) Regulations 1991*

Establish a system of transfer notes and record keeping of waste transfers to assist 'waste holders' comply with their duty of care under Section 34 of the EPA 1990.

They must take all reasonable steps to ensure waste is collected, treated, transported and disposed of by licensed operators.

*Environmental Protection Act 1990*

Covers eight aspects of the control of pollution and protection of the environment; Integrated Pollution Control (IPC) and Air Pollution Control identifying industrial processes scheduled for control by the Environment Agency or local authorities (LAS); Waste on Land, imposing a duty of care on anyone who imports, carries, keeps, treats or disposes of waste on land; Statutory Nuisances and Clean Air; Litter; amendments to the Radioactive Substances Act 1960; Genetically Modified Organisms, dealing with the prevention, or minimization of any damage to the environment from the escape or release of GMOs; Nature Conservation; miscellaneous provisions.

*Pollution Prevention and Control Act 1999*

Implements a new system of pollution control, Integrated Pollution Prevention and Control (IPPC), which will eventually replace IPC and LAPC under the Environmental Protection Act 1990.

*Waste Management Licensing Regulations 1994 (as amended)*

Implement in detail the regulatory system for a waste management licence under EPA 1990.

*Water Industry Act 1991*

Sets out the powers and duties of Statutory Undertakers (SUs) with regard to water supply, the provision of sewerage services and consent requirements for the receipt of trade effluents.

*Water Resources Act 1991*

Sets out the duties and powers of the NRA, part of the Environment Agency, in relation to water resources management, abstraction and impounding, control of pollution of water resources, flood defence.

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