


Hazardous Chemicals Handbook

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Preface

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

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. The possible permutations of effects can be very wide and exposure may be to a combination of hazards. 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 degree of containment, and upon the control measures, e.g. 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 1.1. Additional properties, including those in Table 1.2, are relevant to environmental hazards e.g. relating to behaviour on spillage or emission, and determination of permissible levels of 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 4.34.)

A brief discussion of the relevance of physicochemical principles to hazard identification is given in Chapter 3. Relevant toxic and flammable properties, and summaries of appropriate precautions to cater for them during handling, use and disposal, are provided in Chapters 4 and 5 respectively. Reactive hazards are discussed in Chapter 6. The special problems with cryogenic materials and chemicals under pressure, typified by compressed gases, are dealt with in Chapters 7 and 8. The unique problems associated with radioactive chemicals are described in Chapter 10.

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. Thus, within the EC manufacturers must notify the competent authorities when inventories of dangerous substances/preparations in use (Table 1.3) or in store (Table 1.4) reach specified levels. Similarly, in the UK the Planning (Hazardous Substances) Regulations 1992 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 1.5). This will have profound effects for companies putting forward new proposals for storage. The special considerations with large-scale installations are detailed in various texts noted in the Bibliography.

Table 1.1 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

Concentrations, 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 (LC₅₀)Lethal dose (LD₅₀)*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

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. However, 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 atmospheric monitoring; this is summarized in Chapter 9. General safety considerations, administration and systems of work requirements, including elementary first aid, are summarized in Chapter 11. 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, emergency procedures, arise when marketing and transporting chemicals. While – as with Chapter 11 and with control measures generally – what is required will vary with specific legislation, basic requirements are summarized in Chapter 12.

Table 1.2 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

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 Chapter 13.

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 14. 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 15.

Table 1.3 List of substances for the application of Article 5 (Annex III), 82/501/EEC

The quantities set out below relate to each installation or group of installations belonging to the same manufacturer where the distance between the installations is not sufficient to avoid, in foreseeable circumstances, any aggravation of major-accident hazards. These quantities apply in any case to each group of installations belonging to the same manufacturer where the distance between the installations < approximately 500 m.

Name	Quantity (\geq)
1. 4-Aminodiphenyl	1 kg
2. Benzidine	1 kg
3. Benzidine salts	1 kg
4. Dimethylnitrosamine	1 kg
5. 2-Naphthylamine	1 kg
6. Beryllium (powders, compounds)	10 kg
7. Bis(chloromethyl)ether	1 kg
8. 1,3-Propanesultone	1 kg
9. 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1 kg
10. Arsenic pentoxide. Arsenic(V) acid and salts	500 kg
11. Arsenic trioxide. Arsenious(III) acid and salts	100 kg
12. Arsenic hydride (Arsine)	10 kg
13. Dimethylcarbamoyl chloride	1 kg
14. 4-(Chloroformyl) morpholine	1 kg
15. Carbonyl chloride (Phosgene)	750 kg
16. Chlorine	25 t
17. Hydrogen sulphide	50 t
18. Acrylonitrile	200 t
19. Hydrogen cyanide	20 t
20. Carbon disulphide	200 t
21. Bromine	500 t
22. Ammonia	500 t
23. Acetylene (Ethyne)	50 t
24. Hydrogen	50 t
25. Ethylene oxide	50 t
26. Propylene oxide	50 t
27. 2-Cyanopropan-2-ol (Acetone cyanohydrin)	200 t
28. 2-Propenal (Acrolein)	200 t
29. 2-Propen-1-ol (Allyl alcohol)	200 t
30. Allylamine	200 t
31. Antimony hydride (Stibine)	100 kg
32. Ethyleneimine	50 t
33. Formaldehyde (concentration $\geq 90\%$)	50 t
34. Hydrogen phosphide (Phosphine)	100 kg
35. Bromomethane (Methyl bromide)	200 t
36. Methyl isocyanate	150 kg
37. Nitrogen oxides	50 t
38. Sodium selenite	100 kg
39. Bis(2-chloroethyl) sulphide	1 kg
40. Phosacetim	100 kg
41. Tetraethyl lead	50 t
42. Tetramethyl lead	50 t
43. Promurit (1-(3,4-Dichlorophenyl)-3-triazenethio-carboxamide)	100 kg
44. Chlorfenvinphos	100 kg
45. Crimidine	100 kg
46. Chloromethyl methyl ether	1 kg
47. Dimethyl phosphoramidocyanidic acid	1 t
48. Carbophenothion	100 kg
49. Dialifos	100 kg
50. Cyanthoate	100 kg
51. Amiton	1 kg
52. Oxydisulfoton	100 kg

Table 1.3 Cont'd

Name	Quantity (≥)
53. 00-Diethyl S-ethylsulphinylmethyl phosphorothioate	100 kg
54. 00-Diethyl S-ethylsulphonylmethyl phosphorothioate	100 kg
55. Disulfoton	100 kg
56. Demeton	100 kg
57. Phorate	100 kg
58. 00-Diethyl S-ethylthiomethyl phosphorothioate	100 kg
59. 00-Diethyl S-isopropylthiomethyl phosphorodithioate	100 kg
60. Pyrazoxon	100 kg
61. Pensulfothion	100 kg
62. Paraoxon (Diethyl 4-nitrophenyl phosphate)	100 kg
63. Parathion	100 kg
64. Azinphos-ethyl	100 kg
65. 00-Diethyl S-propylthiomethyl phosphorodithioate	100 kg
66. Thionazin	100 kg
67. Carbofuran	100 kg
68. Phosphamidon	100 kg
69. Tirpate (2,4-Dimethyl-1,3-dithiolane-2-carboxaldehyde O-methylcarbamoyloxime)	100 kg
70. Mevinphos	100 kg
71. Parathion-methyl	100 kg
72. Azinphos-methyl	100 kg
73. Cycloheximide	100 kg
74. Diphacinone	100 kg
75. Tetramethylenedisulphotetramine	1 kg
76. EPN	100 kg
77. 4-Fluorobutyric acid	1 kg
78. 4-Fluorobutyric acid, salts	1 kg
79. 4-Fluorobutyric acid, esters	1 kg
80. 4-Fluorobutyric acid, amides	1 kg
81. 4-Fluorocrotonic acid	1 kg
82. 4-Fluorocrotonic acid, salts	1 kg
83. 4-Fluorocrotonic acid, esters	1 kg
84. 4-Fluorocrotonic acid, amides	1 kg
85. Fluoroacetic acid	1 kg
86. Fluoroacetic acid, salts	1 kg
87. Fluoroacetic acid, esters	1 kg
88. Fluoroacetic acid, amides	1 kg
89. Fluenetil	100 kg
90. 4-Fluoro-2-hydroxybutyric acid	1 kg
91. 4-Fluoro-2-hydroxybutyric acid, salts	1 kg
92. 4-Fluoro-2-hydroxybutyric acid, esters	1 kg
93. 4-Fluoro-2-hydroxybutyric acid, amides	1 kg
94. Hydrogen fluoride	50 t
95. Hydroxyacetoneitrile (Glycolonitrile)	100 kg
96. 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	100 kg
97. Isodrin	100 kg
98. Hexamethylphosphoramide	1 kg
99. Juglone (5-Hydroxynaphthalene-1,4-dione)	100 kg
100. Warfarin	100 kg
101. 4,4'-Methylenebis (2-chloroaniline)	10 kg
102. Ethion	100 kg
103. Aldicarb	100 kg
104. Nickel tetracarbonyl	10 kg
105. Isobenzan	100 kg
106. Pentaborane	100 kg
107. I-Propen-2-chloro-1,3-diol-diacetate	10 kg
108. Propyleneimine	50 t
109. Oxygen difluoride	10 kg
110. Sulphur dichloride	1 t

Table 1.3 Cont'd

Name	Quantity (\geq)
111. Selenium hexafluoride	10 kg
112. Hydrogen selenide	10 kg
113. TEPP	100 kg
114. Sulfotep	100 kg
115. Dimefex	100 kg
116. 1-Tri(cyclohexyl) stannyl-1H-1,2,4-triazole	100 kg
117. Triethylenemelamine	10 kg
118. Cobalt metal, oxides, carbonates, sulphides as powders	1 t
119. Nickel metal, oxides, carbonates, sulphides as powders	1 t
120. Anabasine	100 kg
121. Tellurium hexafluoride	100 kg
122. Trichloromethanesulphenyl chloride	100 kg
123. 1,2-Dibromoethane (Ethylene dibromide)	50 t
124. Flammable substances as defined in Annex IV (c)(i)	200 t
125. Flammable substances as defined in Annex IV (c)(ii)	50 000 t
126. Diazodinitrophenol	10 t
127. Diethylene glycol dinitrate	10 t
128. Dinitrophenol, salts	50 t
129. 1-Guanyl-4-nitrosaminoguanyl-1-tetrazene	10 t
130. Bis (2,4,6-trinitrophenyl)amine	50 t
131. Hydrazine nitrate	50 t
132. Nitroglycerine	10 t
133. Pentatrythritol tetranitrate	50 t
134. Cyclotrimethylene trinitramine	50 t
135. Trinitroaniline	50 t
136. 2,4,6-Trinitroanisole	50 t
137. Trinitrobenzene	50 t
138. Trinitrobenzoic acid	50 t
139. Chlorotrinitrobenzene	50 t
140. N-Methyl-N,2,4,6-N-tetranitroaniline	50 t
141. 2,4,6-Trinitrophenol (Picric acid)	50 t
142. Trinitrocresol	50 t
143. 2,4,6-Trinitrophenetole	50 t
144. 2,4,6-Trinitroresorcinol (Styphnic acid)	50 t
145. 2,4,6-Trinitrotoluene	50 t
146. Ammonium nitrate ⁽¹⁾	2500 t
Ammonium nitrate in the form of fertilizer ⁽²⁾	5000 t
147. Cellulose nitrate (containing > 12.6% nitrogen)	100 t
148. Sulphur dioxide	250 t
149. Hydrogen chloride (liquefied gas)	250 t
150. Flammable substances as defined in Annex IV (c)(iii)	200 t
151. Sodium chlorate ⁽³⁾	250 t
152. tert-Butyl peroxyacetate (concentration \geq 70%)	50 t
153. tert-Butyl peroxyisobutyrate (concentration \geq 80%)	50 t
154. tert-Butyl peroxy maleate (concentration \geq 80%)	50 t
155. tert-Butyl peroxy isopropyl carbonate (concentration \geq 80%)	50 t
156. Dibenzyl peroxydicarbonate (concentration \geq 90%)	50 t
157. 2,2-Bis (tert-butylperoxy) butane (concentration \geq 70%)	50 t
158. 1,1-Bis (tert-butylperoxy) cyclohexane (concentration \geq 80%)	50 t
159. Di-sec-butyl peroxydicarbonate (concentration \geq 80%)	50 t
160. 2,2-Dihydroperoxypropane (concentration \geq 30%)	50 t
161. Di-n-propyl peroxydicarbonate (concentration \geq 80%)	50 t
162. 3,3,6,6,9,9-Hexamethyl-1,2,4,5-tetroxacyclononane (concentration \geq 75%)	50 t
163. Methyl ethyl ketone peroxide (concentration \geq 60%)	50 t
164. Methyl isobutyl ketone peroxide (concentration \geq 60%)	50 t
165. Peracetic acid (concentration \geq 60%)	50 t
166. Lead azide	50 t
167. Lead 2,4,6-trinitroresorcin oxide (Lead styphnate)	50 t

Table 1.3 Cont'd

<i>Name</i>	<i>Quantity (≥)</i>
168. Mercury fulminate	10t
169. Cyclotetramethylenetetranitramine	50t
170. 2,2',4,4',6,6'-Hexanitrostilbene	50t
171. 1,3,5-Triamino-2,4,6-trinitrobenzene	50t
172. Ethylene glycol dinitrate	10t
173. Ethyl nitrate	50t
174. Sodium picramate	50t
175. Barium azide	50t
176. Di-isobutyl peroxide (concentration ≥ 50%)	50t
177. Diethyl peroxydicarbonate (concentration ≥ 30%)	50t
178. tert-Butyl peroxy-pivalate (concentration ≥ 77%)	50t
179. Liquid oxygen	2000t
180. Sulphur trioxide	75t

⁽¹⁾ Ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate is >28% by weight, and aqueous solutions of ammonium nitrate where the concentration of ammonium nitrate is >90% by weight.

⁽²⁾ Straight ammonium fertilizers which comply with Directive 80/876/EEC and compound fertilizers where the nitrogen content is >28% by weight (a compound fertilizer contains ammonium nitrate plus phosphorus and/or potash).

⁽³⁾ Where this substance is in a state which gives it properties capable of creating a major-accident hazard.

Table 1.4 Storage limits (Directive 88/610/EEC – see also 86/216/EEC and 82/501/EEC)

This applies to storage of dangerous substances and/or preparations at any place, installation, premises, building or area of land, isolated or within an establishment, being a site used for the purpose of storage, except where that storage is associated with an installation covered by Annex I and where the substances in question appear in Annex III (see Table 1.3).

The quantities set out below in Parts 1 and 2 relate to each store or group of stores belonging to the same manufacturer where the distance between the stores is not sufficient to avoid, in foreseeable circumstances, any aggravation of major-accident hazards. These quantities apply in any case to each group of stores belonging to the same manufacturer where the distance between the stores is less than 500 m.

The quantities to be considered are the maximum quantities which are, or are liable to be, in storage at any one time.

Part 1 Named substances

Where a substance (or group of substances) listed in Part 1 also falls within a category of Part 2, the quantities set out in Part 1 must be used.

<i>Substances or groups of substances</i>	<i>Quantities (tonnes)</i>	
	<i>For application of Articles 3 and 4</i>	<i>For application of Article 5</i>
1. Acrylonitrile	20	200
2. Ammonia	50	500
3. Chlorine	10	75
4. Sulphur Dioxide	25	250
5. Ammonium nitrate ⁽¹⁾	350	2500
6. Ammonium nitrate in the form of fertilizer ⁽²⁾	1250	10 000
7. Sodium chlorate	25	250
8. Oxygen	200	2000
9. Sulphur trioxide	15	100
10. Carbonyl chloride (phosgene)	0.750	0.750
11. Hydrogen sulphide	5	50

Table 1.4 Cont'd

Substances or groups of substances	Quantities (tonnes)	
	For application of Articles 3 and 4	For application of Article 5
12. Hydrogen fluoride	5	50
13. Hydrogen cyanide	5	20
14. Carbon Disulphide	20	200
15. Bromine	50	500
16. Acetylene	5	50
17. Hydrogen	5	50
18. Ethylene oxide	5	50
19. Propylene oxide	5	50
20. 2-Propenal (acrolein)	20	200
21. Formaldehyde (concentrations $\geq 90\%$)	5	50
22. Bromomethane (methyl bromide)	20	200
23. Methyl isocyanate	0.150	0.150
24. Tetraethyl or tetramethyl lead	5	50
25. 1,2 Dibromoethane (ethylene dibromide)	5	50
26. Hydrogen chloride (liquefied gas)	25	250
27. Diphenylmethane di-isocyanate	20	200
28. Toluene di-isocyanate	10	100

⁽¹⁾ Applies to ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate > 28% by weight and aqueous solutions of ammonium nitrate where the concentration of ammonium nitrate > 90% by weight.

⁽²⁾ Applies to straight ammonium nitrate fertilizers which comply with Directive 80/876/EEC and to compound fertilizers where the nitrogen content derived from the ammonium nitrate > 28% by weight (a compound fertilizer contains ammonium fertilizer together with phosphate and/or potash).

Part 2 Categories of substances and preparations not specifically named in Part 1

The quantities of different substances and preparations ⁽¹⁾ of the same category are cumulative. Where more than one category is specified in the same entry, the quantities of all substances and preparations of the specified categories in that entry must be summed.

Categories of substances and preparations ⁽²⁾	Quantities (tonnes)	
	For application of Articles 3 and 4	For application of Article 5 ⁽³⁾
1. Substances and preparations that are classified as 'very toxic' ⁽⁴⁾	5	20
2. Substances and preparations that are classified as 'very toxic', toxic, ⁽⁵⁾ oxidizing or 'explosive'	10	200
3. Gaseous substances and preparations including those in liquefied form, which are gaseous at normal pressure and which are classified as 'highly flammable'	50	200
4. Substances and preparations (excluding gaseous substances and preparations covered under item 3 above) which are classified as 'highly flammable or extremely flammable' ⁽⁶⁾	5000	50 000

⁽¹⁾ Preparations are mixtures or solutions consisting of two or more substances (Directive 79/831/EEC).

⁽²⁾ The categories of substances and preparations are as defined in the following Directives and their amendments: 67/548/EEC, 73/173/EEC, 77/728/EEC, 78/631/EEC, 88/379/EEC.

⁽³⁾ Articles 5(1)(a) and (b), third indent, apply where appropriate.

⁽⁴⁾ Where the substances and preparations are in a state which gives them properties capable of creating a major-accident hazard.

⁽⁵⁾ This includes flammable gases as defined in Annex IV(c)(i).

⁽⁶⁾ This includes highly flammable liquids as defined in Annex IV(c)(ii).

Table 1.5 Planning (Hazardous Substances) Regulations 1992
Hazardous substances and controlled quantities

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

Table 1.5 Cont'd

<i>Hazardous substance</i>	<i>Controlled quantity</i>
41. 2,2-Bis(tert-butylperoxy)butane (>70%)	5 t
42. 1,1-Bis(tert-butylperoxy)cyclohexane (>80%)	5 t
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:	
(i) cellulose nitrate to which the Explosives Act 1875 applies; or	50 t
(ii) solutions of cellulose nitrate where the nitrogen content of the cellulose nitrate $\leq 12.3\%$ by weight and the solution contains ≤ 55 parts of cellulose nitrate per 100 parts by weight of solution.	
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
Part C Flammable substances (unless specifically named in Parts A and 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 ≤ 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 $<0^{\circ}\text{C}$ (measured at 1 bar absolute), when held under refrigeration or cooling at a pressure ≤ 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 $<21^{\circ}\text{C}$.	10 000 t

^(a) S.R. & O. 1937/54.^(b) S.R. & O. 1947/805.^(c) S.R. & O. 1919/869.^(d) 1875 c.17.^(e) OJ No L250, 23.9.80, p. 7

Terminology

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.

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.

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 if catalyst is present.)

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.

CHRONIC Occurring for a prolonged period.

CHRONIC TOXICITY Adverse health effects in a living organism resulting from repeated daily exposures to a chemical for a significant part of the organism's lifespan.

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.

CONFINED SPACE A boiler, chamber, pipe, tank, chemical reactor or storage vessel, sewer, vat, flue or similar space into which entry must be controlled by a permit-to-work.

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

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

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

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 $>3\text{ m}$ capacity. (The Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981.)

Defined substances covered by a comprehensive system to inform consumers of potential dangers and to reduce the hazard when carried by road. (The Classification, Packaging and Labelling of Dangerous Substances Regulations 1984.)

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 Road Traffic (Carriage of Dangerous Substances in Packages etc.) Regulations 1986.)

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

DUST Solid particles generated by mechanical action, present as airborne contaminant (e.g. $<76\mu\text{m}$ in size).

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.

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, which may lead to runaway conditions.

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 µm) that have condensed from the vapour state.

HAZARD The inherent property of a substance capable of causing harm (e.g. toxicity, radioactivity, flammability, explosivity).

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

HYGIENE STANDARD See OES, MEL, TLV.

LC₅₀ The calculated concentration of a substance that causes death in 50% of a population under prescribed conditions in a prescribed period of time (normally expressed as ppm or mg/m³ for gases, mg/l for liquids).

LD₅₀ 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.)

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

LEL, LOWER FLAMMABLE (OR EXPLOSIVE) LIMIT The lowest concentration of vapour/gas in air at a given pressure and temperature that will propagate a flame when exposed to an ignition source.

MAJOR HAZARD An industrial activity involving certain dangerous substances which have the potential to give rise to serious injury or damage beyond the immediate vicinity of the workplace.

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 Schedule 1 of COSHH Regulations.)

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

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.)

OXYGEN DEFICIENCY Depletion of oxygen content in an atmosphere to below the normal 21%. Exposure to <18% must not be permitted.

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

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.

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

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.

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 1985.)

RESPIRABLE DUST That fraction of total inhalable dust which penetrates to the gas exchange region of the lung.

RESPIRATORY SENSITIZER A substance that may cause sensitization on inhalation, causing, e.g., asthma, rhinitis or extrinsic allergic 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.

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.

SMOKE Particulate matter (usually <0.5 μm in diameter) in air resulting usually from combustion, including liquids, gases, vapours and solids.

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.

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.

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 The fraction of airborne dust which enters the nose and mouth during breathing and is available for deposition in the respiratory tract.

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

UVCE, UNCONFINED VAPOUR CLOUD EXPLOSION Explosion involving a large mixed vapour/air cloud in the open.

Physicochemistry

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

- | | |
|--------------------------------|--|
| • Inherent chemical properties | Toxic, flammable/explosive, reactive, unstable |
| • Form of chemical | Liquid, solid (briquette, flake, powder), gas, vapour, airborne particulate (including mist, fume, froth, aerosol, dust) |
| • Quantity present | In storage, held up in process stages, in the working atmosphere 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 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 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.

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

$$p_a = H x_a$$

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.
- 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^3 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, molten 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.

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.)

Density differences of gases and vapours

As an approximation, at constant pressure,

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

Since few chemicals (e.g. hydrogen, methane, ammonia) have a molecular weight less than that of air, under ambient conditions most gases or vapours are heavier than air. For example, for common toxic gases refer to Table 3.1; for flammable vapours refer to Table 5.1. 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.
- 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

Table 3.1 Densities of some toxic gases and vapours relative to air at 20°C

	<i>Density gas/ density of air</i>	<i>Molecular weight</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

unvented will tend to accumulate at high level. This is an important consideration with piped natural gas and in the use of hydrogen (refer to Table 8.10).

- 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 isolate a combustion process in a gas-fired appliance, but must be sound in construction and unrestricted to avoid leaks.
- The density of air saturated with a chemical vapour may not differ significantly from that of air itself. Refer to Table 3.2. This is an important consideration when designing ventilation systems.

Table 3.2 Relative densities of air saturated with selected chemicals at 25°C

	<i>Relative density of saturated air (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 of liquid chemicals vary widely, e.g. for the majority of hydrocarbon fuels s.g. <1.0 but for natural oils and fats 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.
- 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.

Effects of particle size

Airborne particulate matter may comprise liquid (aerosols, mists or fogs) or solids (dust, fumes). Refer to Figure 4.2. In either case dispersion, by spraying or fragmentation, will

Table 3.3 Terminal velocities of particles of different sizes

<i>Diameter (μm)</i>	<i>Rate of fall (m/s)</i>
5000	9
1000	4
500	3
100	3×10^{-1}
50	75×10^{-3}
10	3×10^{-3}
5	75×10^{-5}
1	36×10^{-6}
0.5	10×10^{-6}
0.1	36×10^{-8}

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 3.3. 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 5.2. The hazard increases with decreasing size.
- Particles in the respirable size range, i.e. about $0.5\text{--}7\mu\text{m}$, 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 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

$$N = K \cdot A (\Delta C)_m$$

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.
- 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 11.17).

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 3.4. 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 semirefri-

Table 3.4 Critical temperature and pressure data for common gases

	<i>Critical temperature (°C)</i>	<i>Critical 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

gerated with the temperature below ambient but the vapour pressure above atmospheric pressure. Of the gases listed in Table 3.5, all those with critical temperatures below ambient must be maintained under refrigeration to keep them in the liquid phase.

- 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 3.5 Gases commonly stored in liquefied form

Gas	Boiling point at 1 bar a (°C)	Liquid density at boiling point (kg/m ³)	Volume ratio of gas (1 bar a, 20°C) to liquid (at boiling point)	Vapour pressure at 38°C (bar abs.)	Critical temperature (°C)
Can be stored without refrigeration					
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
Requires refrigeration					
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. Also a reaction which is immeasurably slow at ambient temperature may become rapid if the temperature is raised. As a result:

- Exothermic reactions require control strategies which may involve
 - Use of dilute solutions/emulsions or suspensions rather than bulk reactants;
 - feeding-in one reactant gradually, controlled by T_r ;

Table 3.6 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

Table 3.7 Comparison of corrosion rates by solutions of salts

Salts (type and examples)	Corrosion rates for listed construction materials				
	Carbon steel	304 SS	316 SS	Alloy 400 (65Ni-32Cu)	Nickel 200
Non-oxidizing non-halides					
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
Non-oxidizing halides					
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
Oxidizing non-halides					
Neutral					
e.g. sodium chromate	L ⁽¹⁾	L	L	L	L
sodium nitrite	L ⁽¹⁾	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
Oxidizing halides					
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 µm)

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

- operating under reflux;
- provision of the largest practicable $T = T_r - T_a$, e.g. using refrigeration;
- provision of the largest practicable heat transfer area, e.g. with a jacket, coils and/or an external heat exchange loop, plus good agitation.
- Emergency systems may be required with an exothermic reaction involving
 - provision for emergency chilling;
 - provision for halting the reaction, e.g. if operated continuously, stopping the flow of reactant(s) and/or adding a reaction inhibitor or short-stop or adding a diluent;
 - provision for emergency dumping;
 - provision for venting via, e.g. a knock-out drum and gas scrubbing/incineration facility.

These systems may also be necessary on ancillary vessels and storage vessels.

- A critical value of diameter exists when scaling-up a conventional agitated cylindrical reaction vessel, since the ratio of heat transfer area: potential heat release is inversely proportional to diameter.

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 4.1) or flammable (refer to Table 5.1), 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 (refer to Table 6.1).
- Electrolytic corrosion.
- Reaction due to contaminants, e.g. in reusable containers or in transfer pipelines.
- Reaction with construction materials.
- Slow decomposition of a chemical of limited stability.
- Self-initiated reactions.

The precautions required can be any combination of those in Table 3.6.

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 5.10 shows the 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.

Table 3.8 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	

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 3.7 and 3.8. Corrosion may be promoted, or accelerated, by traces of contaminants.

Whereas corrosion of metals is due to chemical or 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

Table 3.9 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 ₂ SO ₄ HNO ₃ (conc.)	0–70% H ₂ SO ₄ 0–37% HCl 0.80% HF	Acetic acid Formic acid	NaOH (caustic) NH ₄ OH (ammonia)	NaCl NaOCl FeCl ₃		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
Tantalum	V R R	L R N	R R	N N	R R R		R R		Hot oleum (>50°C), strong alkalis, fluoride solutions, sulphur trioxide
Glass/silicates	R R R	R R N	R R	L L	R R R		R R		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
Carbon, impreg. with furan	N L L	— — L	— —	R R	R R R		— —		Strong oxidizers, very strong solvents
Carbon, impreg. with phenolic	N L L	R R L	R R	N R	R R R		R R		Strong alkalis, very strong oxidizers
FEP/TFE	R R R	R R R	R R	R R	R R R		R R ⁽¹⁾		Molten alkali metals, elemental fluorine, strong fluorinating agents
Furan resin	N N V	R L N	L L	R R	R V R		R L ⁽¹⁾		Strongly oxidizing solutions, liquid bromine, pyridine
Phenolic resin	N L V	R R L	L R	N N	R N L		R L ⁽¹⁾		Strong alkalis or alkali salts, very strong oxidizers
Epoxy resin ⁽²⁾	N N V	L R —	L N	R L	R N R		L L ⁽¹⁾		Strong oxidizing conditions, very strong organic solvents

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.

⁽¹⁾ See Table 3.11.⁽²⁾ Epoxy hardener will strongly affect chemical resistance.

Table 3.10 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	Not for highly oxidizing conditions
	Aluminium alloys	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
Hydrochloric	Copper/copper alloys	Not for oxidizing conditions, including air
	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	Fragile
Hydrofluoric	Reinforced plastic	HCl may attack or permeate laminate; temperature limited (<65.5°C); requires excellent engineering design and fabrication quality
	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
Nitric	Impervious graphite	Fragile; limit to below 60% concentration
	Polyvinylidene fluoride	—
	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.
Oleum	Titanium	May ignite in red-fuming nitric acid if water is below 1.5% and nitrogen dioxide is above 2.5%
	Carbon steel	Not for 100–101% H ₂ SO ₄ concentration; limited in temperature
Phosphoric	Glass-lined steel	Limited shock resistance
	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 3.11 Solvent resistance of polymers

Solvent	Example	Thermosetting resins					Thermoplastics					Elastomers				
		Epoxy (120–148°C) Furan (120°C) Phenolic (93°C) Polyester FRP (104°C) (Bisphenol-A fumarate) Vinyl ester FRP (93°C) (Low-temperature variety) FEP/TFE (204/260°C) Nylon 6/6 (93–120°C) Polyethylene (65°C) Polypropylene (107°C) Polyvinyl chloride (60°C) Polyvinylidene fluoride (135°C) Butyl rubber (93°C) Natural rubber (65°C) Neoprene (93°C)														
Alcohols	Methanol	G	E	G	G	G	E	P	E	E	E	E	E	E	E	G
Aldehydes	Formaldehyde	G	E	G	G	G	E	E	G	E	E	G	E	G	G	E
Aliphatics	Heptane	G	E	E	G	E	E	G	P	G	G	E	E	P	P	G
Aliphatic amines	Diethylamine	G	E	P	P	P	E	P	G	G	—	G	—	—	—	—
Aromatics (and derivatives)	Benzene	E	G	G	P	P	E	G	P	G	P	G	G	P	P	P
	Aniline	P	G	G	P	P	E	P	G	E	P	G	G	P	P	P
	Phenol	G	G	G	F	P	E	P	G	G	P	G	G	P	P	P
	Xylene	G	E	E	G	G	E	G	P	F	P	G	G	P	P	P
Chlorinated aliphatics	Trichloroethylene	G	G	E	G	P	E	G	P	P	P	E	E	P	P	P
	Ethylene chloride	G	G	G	P	P	E	—	P	F	P	E	E	P	P	P
Ketones	Acetone	G	G	P	G	G	E	G	P	G	P	P	G	P	P	P
Miscellaneous:		P	P	P	P	P	E	F	F	E	P	F	F	P	P	P
Pyridine	Aromatics	—	P	—	P	—	E	F	P	F	P	F	F	P	P	P
Tetrahydrofuran		G	E	P	G	P	E	—	P	P	P	F	—	—	—	—
Furfural																

E Recommended to maximum temperature of product form.

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

F Very limited recommendation; for ambient temperature only.

P Not recommended. Severe attack.

(Temperatures are approximate maxima.)

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 3.9 and 3.10. The resistance of some common polymers to organic solvents is summarized in Table 3.11. The attack process is accelerated by an increase in temperature. The chemical resistance of a range of common plastics is summarized in Table 3.12.

Table 3.12 Chemical resistance of common plastics

Chemical	Resins						
	CPE	LPE	PP	PMP	FEP/ 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 3.12 Cont'd

Chemical	Resins						
	CPE	LPE	PP	PMP	FEP/ 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 3.12 Cont'd

Chemical	Resins						
	CPE	LPE	PP	PMP	FEP/ 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 3.12 Cont'd

Chemical	Resins						
	CPE	LPE	PP	PMP	FEP/ 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.

Toxic chemicals

Exposures to chemicals may involve solids, liquids, or airborne matter as mists, aerosols, dusts, fumes (i.e. μm -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.

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 a toxic effect.

For a classification of airborne contaminants, refer to Table 4.1.

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 though 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 4.34) are listed in Table 4.2.

Table 4.1 Classification of airborne contaminants

<i>Classification</i>	<i>Sub-groups</i>	<i>Examples</i>
Irritants		
Have a corrosive or a vesicant (blistering) effect on moist or mucous surfaces.		
Concentration may be more important than duration of exposure.		
Animals and man react similarly.		
(a) Primary	Upper respiratory	Vapour, gases, mists 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.
<i>Dusts</i>		
Detergents; salts (nickel sulphate, zinc chloride); acids, alkalis, chromates.		

(b) Secondary or allergens	Skin sensitizers Respiratory sensitizers	Epoxy-resins; picryl chloride; or chlor-2-4-dinitrobenzene; <i>p</i> -phenyl diamine. Isocyanates; proteolytic enzymes; <i>p</i> -phenylene diamine; complex salts of platinum; cyanuric chloride.
Asphyxiants Exert an effect by interference with oxidation of tissue. Animals and man react similarly.	Simple anoxia caused by oxygen deficiency in inhaled air. Toxic anoxia caused by damage to the body's oxygen transport or utilization by adverse reaction of biologically active substances.	Carbon dioxide; methane; hydrogen; nitrogen; helium. 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).
Anaesthetics and narcotics Exert principal effects as simple anaesthesia, by a depressant action on the central nervous system.		<div> <div> Acetylene Olefins Ether Paraffins Aliphatic ketones Aliphatic alcohols Esters </div> <div> ↓ Decreasing anaesthetic action compared with other effects. </div> </div>
Systemic poisons Substances which cause injury at other than the site of contact.	Visceral organs in general Haematopoietic (i.e. blood-forming system) Nervous system	Many halogenated hydrocarbons and metals. Benzene; phenols. Carbon disulphide; methanol; phenol; <i>n</i> -hexane; methyl <i>n</i> -butyl ketone; organophosphorus compounds; tetra-alkyl lead compounds.
Respiratory fibrogens		<i>Toxic inorganic substances</i> e.g. Lead, manganese, cadmium, antimony, beryllium, mercury; arsenic; phosphorus; selenium and sulphur compounds, fluorides.
Carcinogens Cancer-producing agents	Skin Respiratory Bladder/urinary tract Liver Nasal Bone marrow	<i>Fibrogenic dusts</i> e.g. Free crystalline silica, (quartz, tridymite, cristobalite), asbestos (chrysotile, amosite, crocidolite etc.), talc. Coal tar pitch dust; crude anthracene dust; mineral oil mist; arsenic. Asbestos; polycyclic aromatic hydrocarbons; nickel ore; arsenic; bis-(chloromethyl) ether; mustard gas. β -naphthylamine; benzidine; 4-aminodiphenylamine. Vinyl chloride monomer. Mustard gas; nickel ore. Benzene.
Inerts		<i>Gases</i> Simple asphyxiants Argon; methane; hydrogen; nitrogen; helium. <i>Particulates</i> e.g. cement, calcium carbonate.

Table 4.2 Materials with an 'SK' notation in list of occupational exposure limits

Acrylamide	Hexachloroethane
Acrylonitrile	Hexahydro-1,3,5-trinitro-1,3,5-triazine
Aldrin	Hexan-2-one
Allyl alcohol	Hydrazine
Allyl 2,3-epoxypropyl ether	Hydrogen cyanide
Aniline	2-Hydroxypropylacrylate
Anisidines, <i>o</i> - and <i>p</i> -isomers	2,2-Iminodi(ethylamine)
Azinphos-methyl	Iodomethane
Aziridine	Malathion
Butan-1-ol	Mercury alkyls
2-Butoxyethanol	Methacrylonitrile
Butylamine	Methanol
γ -BHC	Methomyl
Bromoform	2-Methoxyethanol
Bromomethane	2-Methoxyethyl acetate
2-sec-Butylphenol	Methoxypropanol
Captafol	Methyl acrylate
Carbon disulphide	2-Methylcyclohexanone
Carbon tetrachloride	2-Methyl-4,6-dinitrophenol
Chlordane	4-Methylpentan-2-ol
Chlorinated biphenyls	4-Methylpentan-2-one
2-Chlorobuta-1,3-diene	<i>N</i> -Methyl- <i>N</i> ,-2,4,6-tetranitroaniline
1-Chloro-2,3-epoxy propane	<i>N</i> -Methylaniline
2-Chloroethanol	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	Parathion-methyl
1,3-Dichloropropene	Pentachlorophenol
Dichlorvos	Phenol
Dieldrin	<i>p</i> -Phenylenediamine
2-Diethylaminoethanol	Phenylhydrazine
Di-isopropylamine	Phorate
<i>N,N</i> -Dimethylacetamide	Picric acid
<i>N,N</i> -Dimethylaniline	Piperidine
Dimethyl formamide	Propan-1-ol
Dimethyl sulphate	Propan-2-ol
Dinitrobenzene	Propylene dinitrate
2,4-Dinitrotoluene	Prop-2-yn-1-ol
1,4-Dioxane	Sodium fluoroacetate
Dioxathion	Sulfotep
Endosulfan	Tetrabromoethane
Endrin	Tetraethylpyrophosphate
2-Ethoxyethanol	Tetramethyl succinonitrile
2-Ethoxyethyl acetate	Thallium, soluble compounds
Ethyl acrylate	Tin compounds, organic
Ethylene dinitrate	Toluene
4-Ethylmorpholine	Tricarbonyl (eta-cyclopentadienyl) manganese
2-Furaldehyde	Tricarbonyl (methylcyclopentadienyl) manganese
Furfuryl alcohol	1,1,2-Trichloroethane
Glycerol trinitrate	Trichloroethylene
Heptachlor	Xylene
	Xylidine

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 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 4.3.

Table 4.3 Typical effects of sulphur dioxide concentrations in air

Concentration (ppm)	Response
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
10000	Irritation to moist skin within a few minutes

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. Examples of primary irritants include acids; alkalis; defatting compounds, e.g. organic solvents, surfactants; dehydrating agents; oxidizing agents and reducing agents.

In extreme cases irritant chemicals can have a corrosive action. Corrosive substances can attack and weaken materials of construction, as mentioned in Chapter 3. They can also attack living tissue (e.g. to cause skin ulceration and in severe cases chemical burns), kill cells and possibly predispose to secondary bacterial invasion. Thus while acute irritation is a local and reversible response, corrosion is irreversible 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 4.1) etc. Thus dilute mineral acids may be irritant whereas at higher concentrations they may cause corrosion.

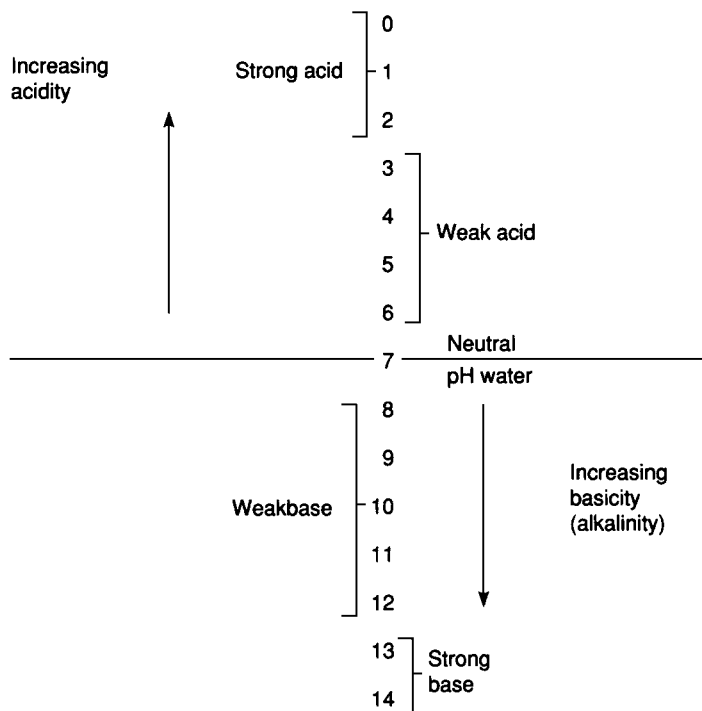


Figure 4.1 *The pH scale*

A summary of the more common corrosive chemicals is given in Table 4.4. 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.
- 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 compounds 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. Intense pain, often delayed, follows 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.

Table 4.4 Common corrosive chemicals

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

Table 4.4 Cont'd

Chlorosilanes	Allyl trichlorosilane	Hexadecyl trichlorosilane
	Amyl trichlorosilane	Hexyl trichlorosilane
	Butyl trichlorophenyl-trichlorosilane	Methyl trichlorosilane
	Cyclohexyl trichlorosilane	Nonyl trichlorosilane
	Dichlorophenyl trichlorosilane	Octadecyl trichlorosilane
	Diethyl trichlorosilane	Octyl trichlorosilane
	Diphenyl dichlorosilane	Phenyl trichlorosilane
	Dodecyl trichlorosilane	Trimethyl trichlorosilane
		Vinyl trichlorosilane
Miscellaneous corrosive substances	<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	Hydrazine
	Benzene sulphonyl chloride	Hydrogen peroxide
	Benzyl dimethylamine	Organic peroxides
	Beryllium nitrate	Phenols
	Catechol	Silver nitrate
	Chlorinated benzenes and toluenes	Soda lime
	Chlorobenzaldehyde	Sodium aluminate
	Chlorocresols	Sodium amide
	Cresols	Sodium bisulphate
	Cyclohexylamine	Sodium bisulphite
	Dibenzylamine	Sodium chromate and dichromate
	Dichlorophenol	Sodium hydride
	Diethyl sulphate	Sodium pyrosulphate
	Diketene	Triethyltetramine
	Dimethyl sulphate	Tritolyl borate
	Hexamethylenediamine	

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. (Also 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, though 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 4.5.

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 4.6. With such sensitizers, complete cessation of contact is often followed by rapid recovery but no further exposure is generally permitted.

Table 4.5 Common industrial skin sensitizers

Coal-tar and its direct derivatives

Acridine
 Anthracene
 Carbazole
 Cresol⁽¹⁾
 Fluorene
 Naphthalene
 Phenanthrene
 Phenol⁽¹⁾
 Pyridine
 Tar

Dyes

Amido-azo-benzene
 Amido-azo-toluene
 Aniline black
 Auramine
 Bismarck brown
 Brilliant indigo, 4 G.
 Chrysoidine
 Crystal and methyl violet
 Erio black
 Hydron blue
 Indanthrene violet, R.R.
 Ionamine, A.S.
 Malachite green
 Metanil yellow
 Nigrosine
 Orange Y
 Paramido phenol
 Paraphenyldiamine
 Pyrogene violet brown
 Rosaniline
 Safranine
 Sulphanthrene pink

Dye intermediates

Acridine and compounds
 Aniline and compounds
 Benzanthrone and compounds
 Benzidine and compounds
 Chloro compounds
 Naphthalene and compounds
 Naphthylamines
 Nitro compounds

Explosives

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

Insecticides

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

Natural resins

Burgundy pitch
 Copal
 Dammar
 Japanese lacquer
 Pine rosin
 Wood rosin

Oils

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

Photographic developers

Bichromates
 Hydroquinone
 Metol
 Para-amido-phenol
 Paraformaldehyde
 Paraphenyldiamine
 Pyrogallol

Plasticizers

Butyl cellosolve stearate
 Diamyl naphthalene
 Dibutyl tin laurate
 Dioctylphthalate
 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

Table 4.5 Cont'd

Synthetic resins	
Acrylic	Sulphonamide formaldehyde
Alkyd	Urea formaldehyde
Chlorobenzols	Urethane
Chlorodiphenyls	Vinyl
Chloro-naphthalenes	
Chlorophenols	Others
Cumaron	Enzymes derived from <i>B. subtilis</i>
Epoxies	
Melamine formaldehyde	
Phenol formaldehyde	
Polyesters	

⁽¹⁾ Compounds which also act as primary irritants.

Table 4.6 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	Adhesives, plastics, moulding resins and surface 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	Manufacture, dispensing
Cimetidine	Manufacture of cimetidine tablets
Wood dusts (hardwoods)	Furniture manufacture
Ispaghula powder	Manufacture of bulk laxatives
Castor bean dust	
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

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 4.7).

Table 4.7 Typical effects of depleted oxygen levels in air

Oxygen concentration (%)	Effect
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 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 of the particle. Figure 4.2 gives typical particle size ranges for particles from various sources. The critical size of dust (and aerosol) particles is 0.5 to 7 μm , 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.

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 4.8 indicates the approximate free silica content of various materials; Table 4.9 lists a range of silica-containing materials according to type.

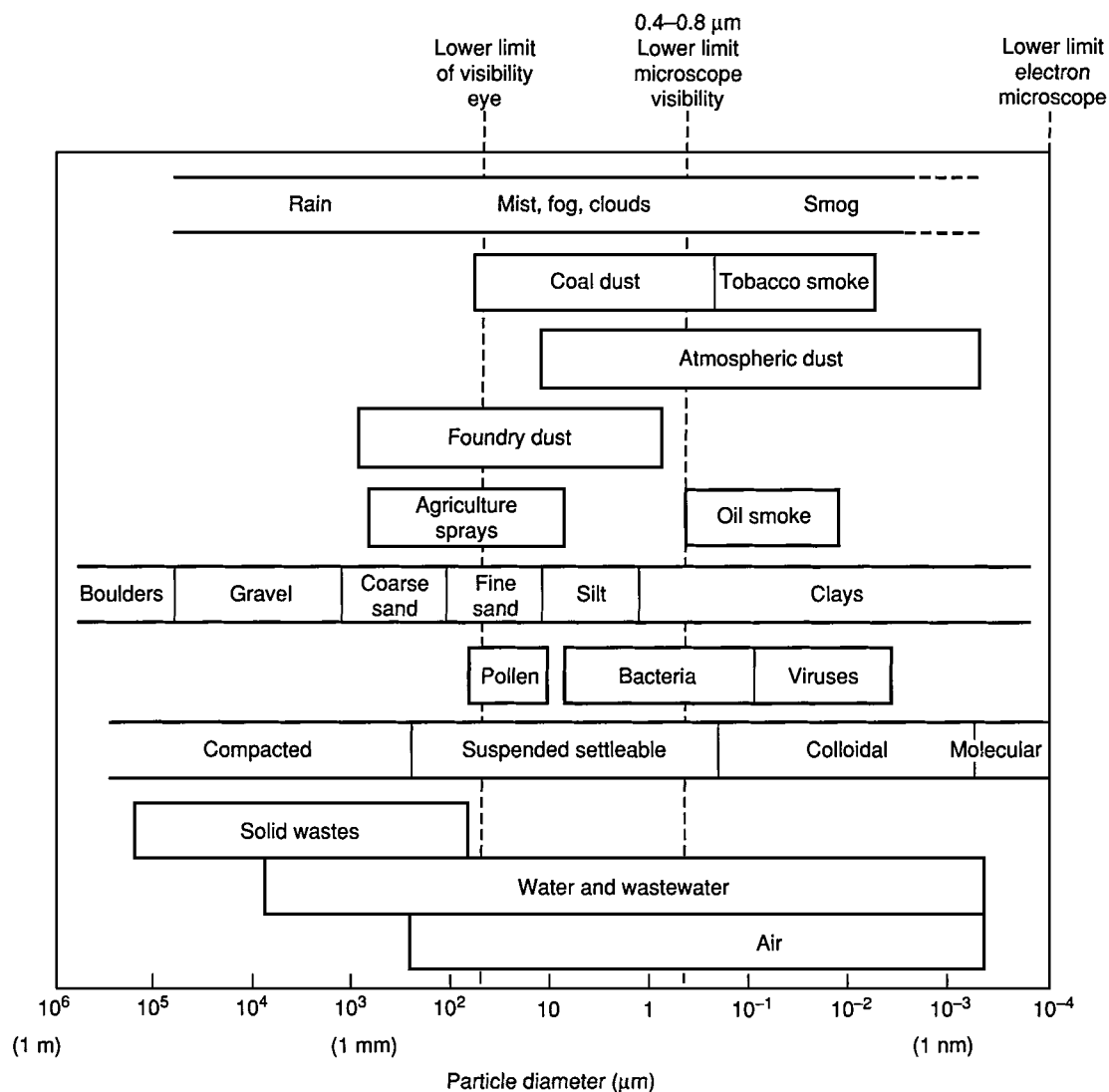


Figure 4.2 Typical particle size ranges

Table 4.8 Crystalline SiO_2 in various materials

Material	Normal range crystalline SiO_2 (%)
Foundry moulding sand	50–90
Pottery ware 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 4.9 Types of silica-containing dusts

Crystalline free silica (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 55). Others, e.g. talc, mica, vermiculite, have caused a silicatosiis 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.

Carcinogens

Cancer is a disorder of the body's control of the growth of cells. For a list of examples of human chemical carcinogens, and the relevant target organs, refer to Table 4.10.

Table 4.10 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
	Pleura and peritoneum – mesothelioma
	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)
	Lung – carcinoma
Haematite mining (underground)	Respiratory tract – carcinoma
Isopropanol manufacture (strong acid process)	
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
	Brain
	Lung – carcinoma
	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
Dimethylcarbamoyl 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

Substances which may be linked to cancer in humans

Chloramphenicol	Isopropyl oils
Chlordane/heptachlor	Lead and lead compounds
Chloroprene	Phenobarbital
Dichlorodiphenyltrichloroethane	N-Phenyl-2 naphthylamine
Dieldrin	Phenytoin (diphenylhydantoin)
Epichlorohydrin	Reserpine
Haematite	Styrene
Hexachlorocyclohexane (lindane)	Trichloroethylene
Isoniazid	Tris(aziridinyl)-p-benzoquinone

Precautions in use

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 4.11: 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 and instruction of workers.
- Identification of chemicals by name and code number.
- Segregated storage of incompatible chemicals.
- Identification by labels, numbers, colour coding etc. of vessels, transfer lines and valves.
- Clear, unambiguous operating instructions.
- Segregated disposal of residues, 'empty' sacks, containers etc.

Control strategies in general

Strategies for reducing the risk from toxic chemicals depend 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 or byproducts.

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 4.11 Common sources of toxic atmospheres

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

⁽¹⁾ 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 provisions, e.g. with knock-out and/or scrubbing, filtration or incineration for vapours/gases.

- 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.

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).

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:

- Prewetting 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.
- Time, e.g. performance of cleaning or 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 back-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, 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 11.10 and capture velocities for various applications in Table 11.9.

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 11. 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 11.3.
- 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.
- 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 cleaning.
- Provision of overalls of an appropriate type and their frequent laundering.
- Prompt attention to, and covering of, damaged or perforated areas of skin.
- Avoidance of eating, drinking 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 4.12.

Specific precautions

Ways in which these principles are applied in practice are illustrated below by reference to common, potentially hazardous operations/substances:

- Everyday operations such as painting and welding.
- Toxic dusts such as asbestos.
- Hyperpoisons, e.g. cyanides.
- The handling of substances such as primary irritants/corrosives.
- Common gases such as carbon monoxide or carbon dioxide, inert gases, hydrogen sulphide and oxides of nitrogen.

Table 4.12 Combination of measures for dust and fume control in the rubber industry

<i>Factory process</i>	<i>Health hazard</i>	<i>Control measures</i>
Drug room	Dust from 'small drugs' (complex organic compounds)	Substitution Master batches Prewriteghed, sealed bags Dust-suppressed chemicals Local exhaust ventilation Care in handling
	Dust from bulk fillers and whittings	Local exhaust ventilation Care in handling
	Dust from carbon black	Master batches Local exhaust ventilation Totally enclosed systems Not by 'careful handling' alone
	Skin contact with process oils	Direct metering into mixer Care in handling and protective clothing.
Compounding	Dust	Local exhaust ventilation Master batches Prewriteghed, sealed bags Dust-suppressed chemicals Care in handling
	Fume	Local exhaust ventilation Removal of hot product from workroom – cool before handling
	Skin contact with process oils	Direct metering Care in handling and protective clothing
Moulding	Fume	Local exhaust ventilation Removal of hot product from workroom – cool before handling Deflection by shields
Calendering and extruding	Fume	Local exhaust ventilation Water cooling of extrudate
	Dust from release agents (chalk stearate or talc)	Substitution of wet methods Enclosure and local exhaust ventilation
Curing	Fume	Local exhaust ventilation at autoclave door and storage racks Allow autoclave to cool before opening
Spreading	Fume	Local exhaust ventilation Care in handling mixes

- Liquids which pose a health hazard due to volatilization, e.g. mercury, or as a result of the presence of impurities, e.g. mineral oils.
- Insecticides.

Painting

Industrial painters may suffer adverse health effects from overexposure to paint by skin contact or accidental ingestion, from excessive inhalation of paint aerosol or solvent vapour, or from exposure to thermal degradation products from heated paint or plastic coatings (Table 4.13).

Precautions for paintwork are summarized in Table 4.14.

Table 4.13 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 Natural drying oils Cellulose derivatives Alkyd resins Epoxy resins (uncured) Phenol-formaldehyde resins Polystyrene Acrylic resins Natural and synthetic rubbers	Carbon monoxide Aldehydes (particularly formaldehyde, acrolein and unsaturated aldehydes) Carboxylic acids Phenols Unsaturated hydrocarbons Monomers, e.g. from polystyrene and acrylic resins
Carbon, hydrogen, nitrogen and possibly oxygen	Amine-cured epoxy resins Melamine resins Urea-formaldehyde resins Polyvinyl pyridine or pyrrolidine Polyamides Isocyanate (polyurethanes) 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 Halogenated rubbers PTFE and other fluorinated polymers Thiourea derivatives Sulphonamide resins Sulphochlorinated compounds	As above, but also halogenated compounds. These may be particularly toxic when fluorine is present Hydrogen halides Carbonyl chloride (phosgene) Hydrogen sulphide Sulphur dioxide

Table 4.14 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.

Full use of any spray booth, enclosure, exhaust ventilation or dilution systems, and automatic handling equipment.

Full use, where appropriate, of ventilation, e.g. by opening doors, windows.

Prompt attention to any damaged or malfunctioning equipment.

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 skin contact and ingestion of chemicals by:

- Use of protective clothing and eye protection.
- Use of barrier cream and skin conditioning cream.

Table 4.14 Cont'd

- 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.

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

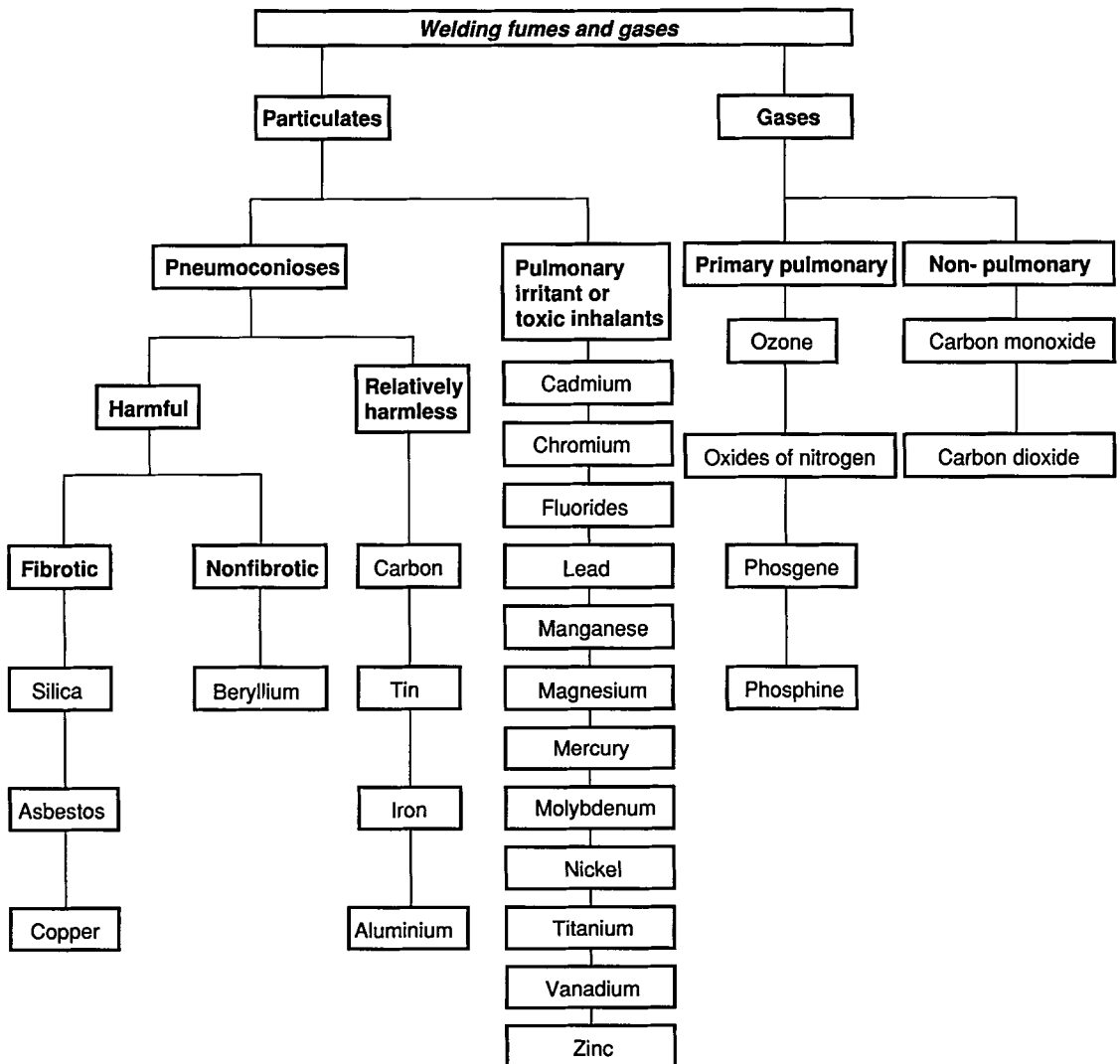


Figure 4.3 Possible constituents in welding fumes and their effects

quantity generated depends upon the type of process. A summary of the possible emissions is given in Figure 4.3. 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 4.13.

Measures to control welding fume include process modifications, engineering controls, system of work and administrative action as summarized in Figure 4.4.

Asbestos

This ubiquitous material finds 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 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 4.15.

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 4.16. 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.

Although organocyanides (alkyl cyanides, nitriles or carbonitriles), in which the cyanide group is covalently bonded, as a class tend to be less toxic than hydrogen cyanide, many are toxic in their own right by inhalation, ingestion or skin absorption, some with the ability to generate hydrogen cyanide under certain conditions e.g. on thermal degradation.

The properties of selected cyanides of industrial importance are summarized in Table 4.17.

Irritants and corrosives

As a class, primary irritants are the most widely encountered 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 4.4) 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, inorganic anhydrous acids (Tables 4.19 and 4.21).

Table 4.18 lists the properties of selected organic acids. Typical precautions for work with irritant and corrosive chemicals are listed in Table 4.22.

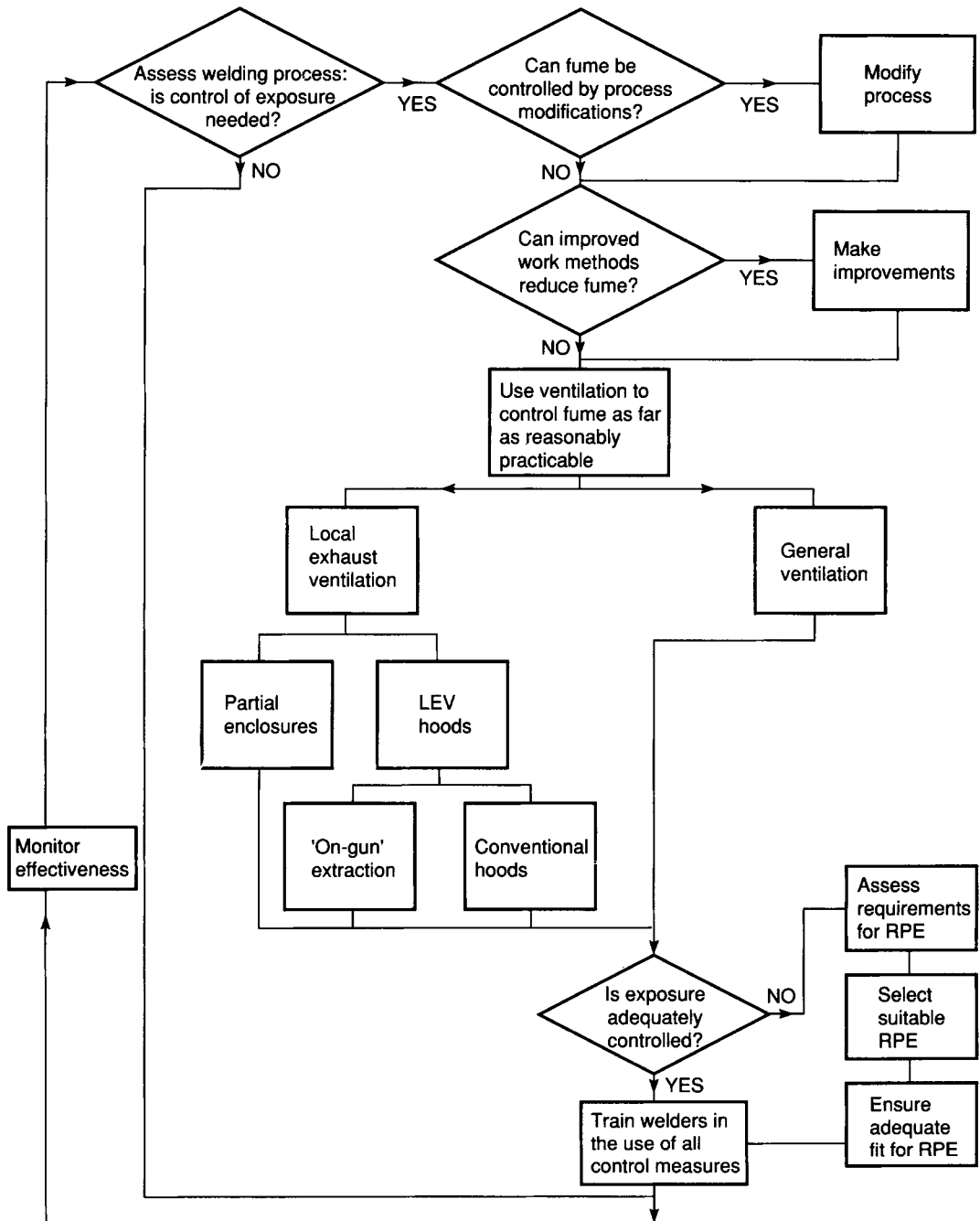


Figure 4.4 Measures to control welding fume

Table 4.15 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:

- Identify the type of asbestos (or assume that it is crocidolite or amosite, to which stricter controls are applicable than to chrysotile).
- Determine the nature and degree of exposure.
- Set out steps to be taken to prevent that exposure, or reduce it to the lowest level reasonably practicable.

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

Maximum exposures to dust levels are set by control limits. (refer to Table 4.34). These are expressed as fibres per millilitre, measured or averaged over 4 hrs or 10 min:

	4 hrs	10 min
chrysotile (white asbestos)	0.5	1.5
amosite (brown asbestos)	0.2	0.6
crocidolite (blue asbestos)	0.2	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:

- Suitable systems of work
- Exhaust ventilation equipment
- Other technical measures
- All of these techniques if reasonably practicable

If the dust level is, or could be, above the control limit an employer must:

- Provide suitable respiratory protective equipment and ensure that it is used properly
- 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:

	over 12 weeks
chrysotile	120
amosite	48
crocidolite	48

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'.

Other provisions

There are also requirements for an employer to:

- Monitor the exposure of employees to asbestos where appropriate
- 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
- Provide protective clothing for workers when a significant quantity of asbestos is liable to be deposited on their clothes
- Check that the plant or premises where work with asbestos is carried out is kept clean
- Make sure that there are adequate washing and changing facilities
- Provide separate storage areas for any protective clothing and respiratory protective equipment required, and for personal clothing
- Make sure that all asbestos articles, substances and products for use at work are specially labelled
- Keep raw asbestos and asbestos waste sealed and labelled

Table 4.16 Toxic effects of hydrogen cyanide

<i>Concentration in air (ppm)</i>	<i>Effect</i>
2–5	Odour detectable by trained individual
10	(UK MEL 10 mg/m ³ 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

Table 4.17 Selected cyano compounds

<i>Chemical</i>	<i>Toxicity</i>	<i>Properties</i>
Acetone cyanohydrin (Oxyisobutyric nitrile) <chem>(CH3)2C(OH)CN</chem>	Highly toxic by inhalation or ingestion Irritating and moderately toxic upon skin contact Readily decomposes to HCN and acetone at 120°C, or at lower temperatures when exposed to alkaline conditions	Colourless combustible liquid Flash point 73°C Ignition temperature 68.7°C Completely soluble in water
Acetonitrile (Methyl cyanide) <chem>CH3CN</chem>	Highly toxic by ingestion, inhalation or skin absorption Insufficient warning properties. Lethal amounts can be absorbed without great discomfort High concentrations rapidly fatal Possibility of severe delayed reactions	Colourless liquid with ether odour and sweet burning taste Flash point 73°C Ignition temperature 52.3°C Flammable limits 4.4%–16%
Acrylonitrile (Vinyl cyanide) <chem>CH2CHCN</chem>	Closely resembles HCN in toxic action Poisonous by inhalation, ingestion or skin absorption Emits cyanides when heated or contacted by acids or acid fumes Symptoms: flushed face, irritation of eyes and nose, nausea etc.	Colourless flammable liquid with mild, faintly pungent odour Flash point 0°C. Dilute water solutions also have low flash point
Adiponitrile (Tetramethylene cyanide) <chem>CN(CH2)4CN</chem>	Can behave as a cyanide when ingested or otherwise absorbed into the body Combustion products may contain HCN	Water-white, practically odourless liquid Flash point 93°C Specific gravity 0.97 Vapour density 3.7
Calcium cyanide <chem>Ca(CN)2</chem>	Reacts with air moisture to release HCN. If finely ground and the relative humidity of the air is >35%, this can occur fairly rapidly Releases HCN slowly on contact with water or CO ₂ , or rapidly with acids Do not handle	Nonflammable white powder or crystals
Cyanogen (Ethane dinitrile, Prussite) <chem>(CN)2</chem>	Highly poisonous gas similar to HCN	Colourless flammable gas with a pungent almondlike odour, becoming acrid in higher concentrations Water soluble Vapour density 1.8

Table 4.17 Cont'd

<i>Chemical</i>	<i>Toxicity</i>	<i>Properties</i>
Cyanogen bromide (Bromine cyanide) CNBr	Extremely irritating and toxic vapours Contact with acids, acid fumes, water or steam can produce toxic and corrosive fumes	Transparent crystals with a penetrating odour Melting point 52°C Boiling point 61°C Vapour density 3.6 Water soluble
Cyanogen chloride (Chlorine cyanide) CNCl	Poisonous liquid or gas Vapour highly irritating and very toxic	Colourless liquid with a strong irritating smell Boiling point 13°C Vapour density 2.1
Potassium cyanide KCN	On exposure to air, gradually decomposes to release HCN Poisonous by ingestion, inhalation or skin absorption Do not handle with bare hands. Strong solutions may be corrosive to the skin	Nonflammable white lumps or crystals Faint odour of bitter almonds Completely water soluble
Sodium cyanide NaCN	Poisonous by inhalation, ingestion or skin absorption Do not handle with bare hands Releases HCN slowly with water, more rapidly with acids	Nonflammable white granules, fused pieces or 'eggs' Odourless when dry; slight almond odour in damp air Completely water soluble

Table 4.18 Common organic acids

<i>Acid</i>	<i>Flash point (°C)</i>	<i>Ignition temperature (°C)</i>	<i>Specific gravity (water = 1.0)</i>	<i>Vapour density (air = 1.0)</i>	<i>Boiling point (°C)</i>	<i>Properties</i>
Acetic acid (glacial) (Ethanoic acid) CH ₃ COOH	40	426	1.05	2.07	118	Clear, colourless water-soluble mobile liquid Strong vinegar odour Lower explosive limit 4% Glacial acetic is a concentration of acetic acid >99% Expands on freezing into an icelike solid at 16.6°C; can break containers
Butyric acid (Butanoic acid) CH ₃ (CH ₂) ₂ COOH	72	452	0.96	3.04	163	Colourless water-soluble oily liquid with strong odour
Formic acid HCOOH	69	601	1.22	1.59	100	Colourless water-soluble fuming liquid with pungent penetrating odour Glacial acid freezes at 8°C Decomposes slowly in storage, liberating carbon monoxide Sufficient gas pressure can accumulate in tightly sealed tank to cause rupture or leakage Common concentrations all >90%
Propionic acid (Methylacetic acid) CH ₃ CH ₂ COOH	54	512	0.99	2.56	141	Colourless liquid with slightly pungent and rancid odour

Table 4.19 Halogens

<i>Halogen</i>	<i>Melting point (°C)</i>	<i>Boiling point (°C)</i>	<i>Vapour density (air = 1.0)</i>	<i>Threshold limit value (ppm)</i>	<i>Reactivity and oxidizing strength</i>	<i>Appearance and state at 21°C</i>	<i>Colour of gas/vapour</i>
Fluorine (F ₂)	−217	−188	1.3	0.1	Extremely active	Pale yellow gas	Pale yellow
Chlorine (Cl ₂)	−101	−34	2.5	1.0	Very active	Greenish-yellow gas. Amber liquid at 5.8 bar pressure.	Greenish-yellow
Bromine (Br ₂)	−6.6	+59	5.5	0.1	Active	Dark red liquid	Dark red to reddish- brown
Iodine (I ₂)	+113	+185 ⁽¹⁾	8.6	0.1	Least active	Bluish-black lustrous solid	Violet

⁽¹⁾ Readily sublimes at lower temperatures.

Table 4.20 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

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 4.20.

Table 4.21 Common anhydrous acids

<i>Chemical</i>	<i>Melting point (°C)</i>	<i>Boiling point (°C)</i>	<i>Typical cylinder pressure at 21°C (bar)</i>	<i>Vapour density (air = 1.0)</i>	<i>Properties</i>
Hydrogen bromide (Anhydrous hydrobromic acid) HBr	–86	–69	22	2.8	Colourless, corrosive nonflammable gas with an acrid odour Highly irritating to eyes, skin and mucous membranes Fumes in moist air, producing clouds with a sour taste Freely soluble in water
Hydrogen chloride (Anhydrous hydrochloric acid) HCl	–111	–83	42.4	1.3	Colourless, corrosive nonflammable gas with a pungent odour Considered somewhat more dehydrating and more corrosive than the mists and vapours of hydrochloric acid Fumes in air Very water soluble
Hydrogen fluoride (Anhydrous hydrofluoric acid) HF	–83	19	0.069	0.7	Colourless, corrosive nonflammable liquid or gas with a penetrating odour Highly irritating and poisonous 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 Fumes in air
Hydrogen iodide (Anhydrous hydriodic acid) HI	–51	–35			Colourless, corrosive nonflammable gas with an acrid odour Highly irritating to eyes, skin and mucous membranes Attacks natural rubber Decomposed by light Extremely soluble in water Fumes in moist air

Table 4.22 Precautions in handling primary irritants/corrosives

Avoid contact	<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)</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>
Personal protection	<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>
First aid measures	<p>Investigate all complaints</p> <p>In the case of injury, obtain medical attention rapidly</p>
Emergency measures	<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 <i>quicklime</i> whose reaction with water is exothermic (1 g generates >18 kcal), <i>titanium</i> or <i>tin tetrachloride</i>, 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. Treated with calcium gluconate locally and monitoring of serum calcium levels, with administration of calcium where necessary</p>

Potential sources of carbon monoxide hazards include metal-refining processes, in which it is formed as a byproduct and used as a fuel (LEL 12.5%), and running vehicle engines (particularly petrol-driven) or gas-fired heaters in poorly ventilated confined spaces. It is also a feedstock in the manufacture of a variety of chemicals, e.g. methanol, acetic acid, phosgene and oxo-alcohols.

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 4.23.

If a potential carbon monoxide hazard is identified, or confirmed by atmospheric monitoring, the range of control techniques summarized on pages 47–51 must be applied.

Table 4.23 Typical reactions of persons to carbon monoxide in air

<i>Carbon monoxide (ppm)</i>	<i>Effect</i>
50	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

Carbon dioxide

Carbon dioxide gas can act as an asphyxiant due to displacement of air, resulting in oxygen deficiency (page 43). Sources include:

- Fires.
- Use as an inert gas.
- Discharge of carbon dioxide extinguishers.
- Use of solid ‘cardice’ as a cryogen (page 184).
- Natural processes, e.g. fermentation.
- Water from certain underground strata, due to de-gassing (page 17).
- 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 4.24. Furthermore, the increased respiratory rate may cause increased amounts of other toxic gases, e.g. carbon monoxide in fires, to be inhaled.

The special precautions appropriate for entry into confined spaces are summarized in Chapter 11. In fires, evacuation of burning buildings, prohibition on re-entry and the use of self-contained breathing apparatus by fire-fighters are key precautions.

Table 4.24 Typical reactions of persons to carbon dioxide in air

Carbon dioxide concentration (ppm) (%)		Effect
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

Inert gases

Most inert gases, e.g. nitrogen, argon, helium (and indeed common flammable gases, e.g. hydrogen, methane, propane, butane, acetylene) can generate oxygen-deficient atmospheres – generally, but not always, in confined spaces. They have no colour, smell or taste. Responses at given depleted oxygen levels are summarized in Table 4.7: 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 285).

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 hydro-desulphurization 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 4.25.

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 8.

Table 4.25 Typical effects of hydrogen sulphide concentrations in air

Concentration (ppm)	Response
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

Oxides of nitrogen

Oxides of nitrogen comprise nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), dinitrogen tetroxide (N_2O_4) and dinitrogen pentoxide (N_2O_5). N_2O_5 is a low-melting solid rapidly decomposing in air to $\text{NO}_2/\text{N}_2\text{O}_4$.

Nitrous oxide has no irritating properties and is used extensively as an anaesthetic ('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 TLV (page 73) of 50 ppm is believed sufficiently low to prevent embryofetal toxicity in humans. Nitric oxide is a colourless gas which 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.
- Electrical 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 4.26: the margin

Table 4.26 Effects of nitrogen oxides

Concentration (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 (≤ 1 hour)

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 TLV is 3 ppm with an STEL (page 73) of 5 ppm.

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.

Table 4.27 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

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 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 4.27.

Mineral oil lubricants

Mineral oils are widely used as lubricants, cutting oils, soluble oil coolants etc.

Mineral oils have very low acute toxicities, i.e. oral LD₅₀ 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; carcinogenic activity is reduced by solvent refining of the base stocks. 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^3 as an 8 hr TWA concentration and 10 mg/m^3 as a 10 min STEL concentration. General recommendations for precautions with mineral oils are summarized in Table 4.28.

Table 4.28 General precautions with mineral oils

Avoid all unnecessary contact with mineral and synthetic oils, e.g. by carefully designed work practices
Avoid extreme exposure to oil mist or vapours
Use splash guards and protective clothing (impervious aprons with detachable absorbent fronts will keep oil off body and prevent it dripping onto feet)
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

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, dusts 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 4.29. The range of chlorinated hydrocarbon insecticides (Table 4.30) has, 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 4.31.

Essential precautions with insecticides are summarized in Table 4.32.

Table 4.29 Organophosphate insecticides (see also Table 4.34)

<i>Insecticide</i>	<i>Oral LD₅₀</i> (mg/kg)	<i>Dermal LD₅₀</i> (mg/kg)	<i>UK OES</i> <i>8 hr TWA value</i> (mg/m ³)
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	—
Dicaphon	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
O-ethyl-O-p-nitrophenyl Phenyl 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 LD₅₀ varies according to species of animal, sex, age and health.

Table 4.30 Chlorinated hydrocarbon insecticides (see also Table 4.34)

<i>Insecticide</i>	<i>Oral LD₅₀</i> (mg/kg)	<i>Dermal LD₅₀</i> (mg/kg)	<i>UK OES</i> <i>8 hr TWA value</i> (mg/m ³)
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 LD₅₀ varies according to species of animal, sex, age and health.

Table 4.31 Insecticides, rodenticides, fungicides and herbicides (see also Table 4.34)

<i>Substance</i>	<i>Oral LD₅₀</i> (mg/kg)	<i>Dermal LD₅₀</i> (mg/kg)	<i>UK OES</i> <i>8 hr TWA value</i> (mg/m ³)
Insecticides			
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	—	—
Rodenticides			
Sodium Fluoroacetate	—	—	0.05 SK
Strychnine	—	—	0.15
Thallium Sulphate	—	—	0.1 as TI, SK
Warfarin	—	—	0.1
Fungicides			
Ferbam	17 000	—	10
Formaldehyde	—	—	2.5 MEL
Organic Mercurials	—	—	0.01
Maneb	7500	—	—
Nabam	395	—	—
Pentachlorophenol	—	—	0.5 SK
Ziram	1400	—	—
Herbicides			
2,4-D	375–700 (different acids, salts and esters)	—	10
2,4,5,-T	481–500 (different acids and esters)	—	10
Dinitrocresol (DNOC)	30	—	0.2 SK

SK Can be absorbed through skin.

The LD₅₀ varies according to species of animal, sex, age and health.

Table 4.32 Guidance on safety with pesticides

Approval	In the UK only approved pesticides may be supplied and used Each product has an approval number and conditions of use
Storage requirements	Suitable siting Adequate capacity and construction Designed to hold spillage Properly lit and ventilated Fire- and frost-resistant Designed so that containers can be safely stacked and moved Clearly marked Kept locked except when in use
Competence	Every user must be competent (Certificate of Competence required in UK)
Information	Workers must be supplied with sufficient information and guidance
Evaluation of possible problems	Product selection How to comply with the conditions of approval Selection of protective clothing How to avoid spray drift How to avoid environmental damage Need to warn neighbours and others who may be affected etc.
Training requirements	Pesticide legislation Decisions on whether a pesticide has to be used Selection of appropriate pesticide Interpretation of labels and codes of practice Hazards and risks to human health/the environment Selection and use of engineering controls and protective clothing Calibration and safe operation of application equipment Safe storage and disposal of pesticides Emergency action in case of poisoning or contamination How to contain and deal with accidental spillage Constraints imposed by weather or other factors Appropriate record keeping Need for exposure monitoring/health surveillance
Exposure control	Use engineering/technical means, e.g. Low-level filling bowls Suction probes Closed handling systems Soluble packs In-cab electronic sprayer controls Hydraulic boom-folding (These measures should be used in preference to protective clothing)
Disposal	Minimize disposal requirements by careful estimation of needs and correct measurement Dispose of dilute pesticides by using as a spray, in accordance with 'approval', in a safe/ approved area Concentrated, unused pesticides should be stored, returned or disposed of as toxic waste

Hazard assessment

Indicators of toxicity hazards include LD_{50} , LC_{50} , plus a wide range of *in vivo* and *in vitro* 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 can 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 4.33 illustrates the use of LD_{50} values to rank the toxicity of substances.

Table 4.33 Toxicity rating system

Toxicity rating	Commonly used term	LD_{50} Single oral dose for rats (g/kg)	4 hr Vapour exposure causing 2 to 4 deaths in 6-rat group (ppm)	LD_{50} Skin for rabbits (g/kg)	Probable lethal dose for humans
1	Extremely toxic	≤ 0.001	< 10	≤ 0.005	Taste (1 grain)
2	Highly toxic	0.001–0.05	10–100	0.005–0.043	1 teaspoon (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 (250 g)
5	Practically non-toxic	5.0–15.0	10 000–100 000	2.82–22.6	1 quart (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 4.23 and 4.25. 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 4.34 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 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 be aggravated by 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 8hr work day and a 40hr work week to which 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 workers can be exposed continuously for short periods 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

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; for a short-term limit the normal period is ten minutes.

Specific short-term exposure limits are listed by the HSE for those chemicals which pose a risk of acute effects 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 10 min period.

Percutaneous absorption

For most chemicals, inhalation is the main route of entry into the body. However, 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.

Chemicals able to penetrate intact skin are listed in Table 4.2.

MEL/OES

In the UK (under the Control of Substances Hazardous to Health Regulations 1988) 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.

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 9) 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 (mg/m³)</i>
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 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 MEK (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 TLV of the mixture is given by

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

Example. Air contains 0.10 mg/m³ lead (TLV 0.15 mg/m³) and 0.9 mg/m³ sulphuric acid (TLV 1 mg/m³):

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

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 4.35. 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.

Odour thresholds

Some materials possess low odour thresholds: their smell gives warning of pending danger. Others possess odour thresholds well in excess of the hygiene standard. Examples are included in Table 4.34.

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.
- Workers may become acclimatized to a commonly-occurring odour.

Table 4.34 Hygiene standards (see key and notes on pages 95–97)

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Acetaldehyde ^(d)	100	180	150	270	UR	100	180	150	2000
Acetic acid	10	25	15	37		10	25	15	21
Acetic anhydride	5 C	21 C	—	—		—	5	20	39
Acetone ^(e)	750	1780	1000	2380	750	1780	1500	3560	57
Acetonitrile ^(e)	40	67	60	101	40	70	60	105	0.23
Acetylene	—	(f)	—	—	—	(f)	—	—	230
Acetylene dichloride, see 1,2-Dichloroethylene									
Acetylene tetrabromide	1	14	—	—					
Acetylsalicylic acid (aspirin)	—	5	—	—	—	5	—	—	
Acrolein	0.1	0.23	0.3	0.69	0.1	0.25	0.3	0.8	0.61
Acrylamide ^(d)	SK	0.03 ^(g)	—	—	SK	0.3 MEL	—	—	
Acrylic acid ^(h)	SK	2	—	—	10	30	20	60	110
Acrylonitrile ^(d,e)	SK	2 ^(g)	—	—	SK	4 MEL	—	—	0.12
Aldrin ^(d,e)	SK	0.25	—	—	SK	0.25	—	0.75	
Allyl alcohol	SK	2	4*	9.5	SK	2	4	10	1.8
Allyl chloride ^(d)	1	3.0	2	6.0	—	—	—	—	0.84
Allyl glycidyl ether (AGE)	5	23	10	47	SK	5	22	44	
Allyl propyl disulphide	2	12	3	18	—	—	—	—	
α-Alumina, see Aluminium oxide									
Aluminium as Al									
Metal dust	—	10	—	—	UR	10	—	20	
Pyro powders	—	5	—	—	—	—	—	—	
Welding fumes	—	5	—	—	—	—	—	—	
Soluble salts	—	2	—	—	—	2	—	—	
Alkyls (NOC)	—	2	—	—	—	2	—	—	
Aluminium oxide as Al	—	10 ^(a)	—	—	UR	10	—	20	
4-Aminodiphenyl ^(f)	SK	(j)	—	—	—	—	—	—	
2-Aminoethanol, see Ethanolamine									
2-Aminopyridine	0.5	2.0	—	—	0.5	2	2	8	
Amitrole ^(d)	—	0.2	—	—	—	—	—	—	
Ammonia	25	17	35	24	25	17	35	24	4.8
Ammonium chloride fume	—	10	—	20	—	10	—	20	
Ammonium perfluorooctanoate	—	0.1	—	—	—	—	—	—	
Ammonium sulphamate	—	10	—	—	—	10	—	20	
Amosite, see Asbestos									
n-Amyl acetate	100	532	—	—	100	530	150	800	1800
sec-Amyl acetate	125	665	—	—	—	—	150	800	61000
Aniline and homologues ^(d,k)	SK	2	—	—	SK UR	2	10	5	20
Anisidine (o-, p-isomers)	SK	0.1	0.50	—	SK	0.1	0.5	—	1.9
Antimony and compounds, as Sb	—	0.5	—	—	—	0.5	—	—	
Antimony trioxide ^(d)									
Handling and use, as Sb	—	0.5	—	—	UR	0.5 (trioxide and trisulphide)	—	—	
Production	—	(g)	—	—	—	—	—	—	
ANTU	—	0.3	—	—	—	—	—	—	
Argon	—	(f)	—	—	—	(f)	—	—	
Arsenic and soluble compounds, as As ^(d,e)	—	0.2	—	—	—	0.1 MEL (except arsine)	—	—	
Arsenic trioxide production	—	(g)	—	—	—	—	—	—	
Arsine ^(e)	0.05	0.16	—	—	0.05	0.2	—	—	0.10

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Amosite ^(e)		0.5 fibre/cc ^(f)			<div> <div></div> <div>(m)</div> </div>				
Chrysotile ^(e)		2 fibres/cc ^(f)							
Crocidolite ^(e)		0.2 fibre/cc ^(f)							
Other forms ^(e)		2 fibres/cc ^(f)							
Asphalt (petroleum) fumes	—	5	—	—	—	5	—	10	
Atrazine	—	5	—	—	UR	10	—	—	
Azinphos-methyl ^(h)	SK	0.2	—	—	SK	0.2	—	0.6	
Barium, soluble compounds, as Ba	—	0.5	—	—	—	0.5	—	—	
Barium sulphate	—	10 ⁽ⁱ⁾	—	—	—	2 (respirable dust)	—	—	
Benomyl	0.84	10	—	—	—	10	—	15	
Benzene ^(d,e,k,n)	(10) ^(g)	(32) ^(g)	—	—	5	15 MEL	—	—	0.85
Benzenethiol	—	—	—	—	0.5	2	—	—	
Benzene-1,2,4-tricarboxylic acid 1,2-anhydride	—	—	—	—	SEN	0.04	—	—	
Benzidine ^(h)	SK	(j)	—	—	—	—	—	—	
p-Benzoquinone, see Quinone									
Benzoyl peroxide	—	5	—	—	—	5	—	—	
Benzo(a)pyrene ^(h)	—	(g)	—	—	—	—	—	—	
Benzyl butyl phthalate	—	—	—	—	—	5	—	—	
Benzyl chloride ^(d)	1	5.2	—	—	UR	5	—	—	23
Beryllium and compounds, as Be ^(d,e)	—	0.002 ^(g)	—	—	UR	0.002	—	—	
Biphenyl	0.2	1.3	—	—	0.2	1.5	0.6	4	240
2,2-Bis(p-chlorophenyl)-1,1,1-trichloroethane	—	—	—	—	—	1	—	3	
Bis(2,3-epoxypropylether)	—	—	—	—	0.1	0.6	—	—	
Bismuth telluride	—	10	—	—	—	10	—	20	
Se-doped	—	5	—	—	—	5	—	10	
Borates, tetra, sodium salts									
Anhydrous	—	1	—	—	—	1	—	—	
Decahydrate	—	5	—	—	—	5	—	—	
Pentahydrate	—	1	—	—	—	1	—	—	
Boron oxide	—	10	—	—	—	10	—	20	
Boron tribromide	1 C	10 C	—	—	—	—	3	30	
Boron trifluoride	1 C	2.8 C	—	—	—	—	1	3	
Bromacil	1	11	—	—	1	10	2	20	
Bromine	0.1	0.66	0.3	2.0	0.1	0.7	0.3	2	
Bromine pentafluoride	0.1	0.72	—	—	0.1	0.7	0.3	2	2.0
Bromochloromethane, see Chlorobromomethane									
Bromoform	SK	0.5	—	—	SK	0.5	5	—	0.39
1,3-Butadiene ^(d)	10 ^(g)	22 ^(g)	—	—	10	22 MEL	—	—	640
Butane	800	1900	—	—	600	1430	750	1780	0.29
Butanethiol, see Butyl mercaptan									
2-Butanone, see Methyl ethyl ketone (MEK)									
trans-But-2-enal	—	—	—	—	UR	2	6	18	
2-Butoxyethanol (EGBE)	SK	121	—	—	SK	25	120 MEL	—	250
n-Butyl acetate	150	713	200	950	150	710	200	950	390
sec-Butyl acetate	200	950	—	—	200	950	250	1190	
tert-Butyl acetate	200	950	—	—	200	950	250	1190	
Butyl acrylate	10	52	—	—	10	55	—	—	290
n-Butyl alcohol	SK	50 C	152 C	—	SK	50	150	50	150
sec-Butyl alcohol	100	303	—	—	100	300	150	450	38
tert-Butyl alcohol	100	303	150	455	100	300	150	450	2.1
Butylamine	SK	5 C	15 C	—	SK	—	5	15	2.7
n-Butyl chloroformate	—	—	—	—	1	5.6	—	—	
tert-Butyl chromate as CrO ₃ ^(e)	SK	0.1 C	—	—	—	—	—	—	

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	STEL (ppm) ^(a)	STEL (mg/m ³) ^(b)	(ppm)	TWA ^(a) (mg/m ³)	STEL ^(a) (ppm)	STEL ^(a) (mg/m ³)	
<i>n</i> -Butyl glycidyl ether (BGE) ^(m)	25	133	—	—	25	135	—	—	0.71
<i>n</i> -Butyl lactate	5	30	—	—	5	25	—	—	
Butyl mercaptan	0.5	1.8	—	—	—	—	—	—	
<i>o</i> -sec-Butylphenol	SK 5	31	—	—	SK 5	30	—	—	510
<i>p</i> -tert-Butyltoluene	10	61	20	121	—	—	—	—	2.0
Cadmium dusts and salts, as Cd ^(d,k,m)	—	(0.05)	—	—	—	0.05 MEL	—	—	
						(except cadmium sulphide pigments)			
Cadmium oxide ⁽ⁿ⁾	—	(0.05 C)	—	—	—	0.05 MEL	—	0.05 MEL	
Fume, as Cd	—	(0.05)	—	—	—	—	—	—	
Production	—	—	—	—	—	0.04 MEL	—	—	
Cadmium sulphide pigments, respirable dust, as Cd	—	—	—	—	—	—	—	—	
Calcium carbonate	—	10 ⁽ⁿ⁾	—	—	{	10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	1	
						0.5	—	—	
Calcium cyanamide	—	0.5	—	—	—	5	—	—	
Calcium hydroxide	—	5	—	—	—	2	—	—	
Calcium oxide	—	2	—	—	—	10 (total inhalable dust)	—	—	
Calcium silicate ⁽ⁿ⁾	—	10 ⁽ⁿ⁾	—	—	{	5 (respirable dust)	—	—	
						10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	—	
Calcium sulphate	—	10 ⁽ⁿ⁾	—	—	{	10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	—	
						12	3	18	
Camphor, synthetic	2	12	3	19	2	12	3	18	7.3
Caprolactam ^(m)	—	(1)	—	(3)	—	1	—	3	
Dust	—	(20)	—	(40)	—	20	10	40	
Vapour	(4.3)	(20)	(8.6)	(40)	5	0.1	—	—	
Captafol	SK —	0.1	—	—	SK —	5	—	15	
Captan	—	5	—	—	—	5	—	10	
Carbaryl	—	5	—	—	—	0.1	—	7	
Carbofuran	—	0.1	—	—	—	3.5	—	—	
Carbon black ^(d)	—	3.5	—	—	—	15 000	27 000	—	0.067
Carbon dioxide	5000	9000	30 000	54 000	5000	9000	15 000	27 000	92
Carbon disulphide ^(p,k)	SK 10	31	—	—	SK 10	30 MEL	—	—	0.000 50
Carbon monoxide	50	57	400	458	50	55	300	330	
Carbon tetrabromide	0.1	1.4	0.3	4.1	0.1	1.4	0.3	4	
Carbon tetrachloride ^(d,e)	SK 5 ^(k)	31 ^(k)	—	—	SK UR 10	65	20	130	0.052
Carbonyl chloride, see Phosgene	—	—	—	—	—	—	—	—	
Carbonyl fluoride	2	5.4	5	13	—	—	—	—	
Catechol	5	23	—	—	5	20	—	—	
Cellulose (paper fibre)	—	10	—	—	—	10 (total inhalable dust)	—	20	
						5 (respirable dust)	—	—	
Cesium hydroxide	—	2	—	—	—	2	—	—	

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (mg/m ³)		
Chlordane ^(d,e)	SK	—	0.5	—	SK UR	—	0.5	—	2
Chlorinated camphene ^(d)	SK	—	0.5	—	—	—	—	—	—
Chlorinated diphenyl oxide	—	—	0.5	—	—	—	—	—	—
Chlorine	0.5	1.5	1	2.9	0.5	1.5	1	3	3.2
Chlorine dioxide	0.1	0.28	0.3	0.83	0.1	0.3	0.3	0.9	0.011
Chlorine trifluoride	0.1 C	0.38 C	—	—	—	—	0.1	0.4	—
Chloroacetaldehyde	1 C	3.2 C	—	—	—	—	1	3	—
Chloroacetone	SK 1 C	3.8 C	—	—	—	—	—	—	—
α-Chloroacetophenone	0.05	0.32	—	—	0.05	0.3	—	—	1.4
Chloroacetyl chloride ^(m)	(0.05)	(0.23)	—	—	UR 0.05	0.2	—	—	—
Chlorobenzene ⁽ⁿ⁾	(75)	(345)	—	—	50	230	—	—	110
o-Chlorobenzylidene malononitrile	SK 0.05 C	0.39 C	—	—	—	—	—	—	—
Chlorobromomethane ^(a)	200	1060	—	—	200	1050	250	1300	0.50
2-Chloro-1,3-butadiene, see β-Chloroprene	—	—	—	—	—	—	—	—	—
Chlorodifluoromethane ^(a)	1000	3540	—	—	UR 1000	3500	1250	4375	—
Chlorodiphenyl (42% chlorine) ^(e,u)	SK	1	—	—	SK UR	1	—	2	—
Chlorodiphenyl (54% chlorine) ^(d,e,u)	SK	0.5	—	—	SK UR	0.5	—	1	—
1-Chloro-2,3-epoxy propane, see Epichlorohydrin	—	—	—	—	—	—	—	—	—
2-Chloroethanol, see Ethylene chlorohydrin	—	—	—	—	—	—	—	—	—
Chloroethylene, see Vinyl chloride	—	—	—	—	—	—	—	—	—
Chloroform ^(d,e)	10 ^(p)	49 ^(p)	—	—	UR 10	50	50	225	0.12
bis(Chloromethyl)ether	0.001 ^(p)	0.0047 ^(p)	—	—	UR 5	20	—	—	—
Chloromethyl methyl ether ^(d)	(g)	(g)	—	—	—	—	—	—	—
1-Chloro-4-nitrobenzene	—	—	—	—	SK	1	—	2	—
1-Chloro-1-nitropropane	2	10	—	—	—	—	—	—	—
Chloropentafluoroethane	1000	6320	—	—	1000	6320	—	—	—
Chloropicrin ^(a)	0.1	0.67	—	—	0.1	0.7	0.3	2	0.13
β-Chloroprene ^(d,e)	SK 10	36	—	—	SK 10	36	—	—	0.68
3-Chloropropene	—	—	—	—	UR 1	3	2	6	—
o-Chlorostyrene	50	283	75	425	—	—	—	—	—
Chlorosulphonic acid	—	—	—	—	—	1	—	—	—
o-Chlorotoluene ^(a)	50	259	—	—	50	250	—	—	150
2-Chloro-6-(trichloromethyl)pyridine, see Nitrapyrin	—	—	—	—	—	—	—	—	—
Chlorpyrifos ^(a)	—	0.2	—	—	SK	—	0.2	—	0.6
Chromite ore processing (Chromate), as Cr ^(d)	—	0.05 ^(t)	—	—	—	—	—	—	—
Chromium metal	—	0.5	—	—	—	—	0.5	—	—
Chromium (II) compounds, as Cr	—	0.5	—	—	—	—	0.5	—	—
Chromium (III) compounds, as Cr	—	0.5	—	—	—	—	0.5	—	—
Chromium (VI) compounds, as Cr ^(d,e,k)	—	—	—	—	—	—	—	—	—
Water soluble ^(e,k)	—	0.05	—	—	} PR UR	—	—	—	—
Certain water insoluble	—	0.05 ^(p)	—	—		0.05	—	—	—
Chromyl chloride ^(d,e)	0.025	0.16	—	—		—	—	—	—
Chrysene ^(d)	(g)	(g)	—	—	—	—	—	—	—
Chrysotile, see Asbestos	—	—	—	—	—	—	—	—	—
Clopidol ^(a)	—	10	—	—	—	—	—	—	—
Coal dust	—	2 ^(p)	—	—	—	2	—	—	—
	—	(respirable fraction)	—	—	—	—	—	—	—
Coal tar pitch volatiles, as benzene solubles ^(d,e)	—	0.2 ^(p)	—	—	UR	0.14	—	—	—
	—	—	—	—	—	(as cyclohexane solubles)	—	—	—
Cobalt as Co, metal dust and fume ^(d)	—	0.05	—	—	—	0.1	—	—	—
	—	—	—	—	—	(cobalt and compounds)	—	—	—
Cobalt carbonyl as Co	—	0.1	—	—	—	—	—	—	—
Cobalt hydrocarbonyl as Co	—	0.1	—	—	—	—	—	—	—

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	(ppm) ^(a)	(mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	(ppm)	STEL ^(c) (mg/m ³)	
Copper									
Fume	—	0.2	—	—	—	0.2	—	—	
Dusts and mists as Cu	—	1	—	—	—	1	—	2	
Cotton dust, raw	—	0.2 ^(g)	—	—	—	0.5	—	—	
Cresol, all isomers ^(a)	SK 5	22	—	—	SK 5	22	—	—	17 000 (M-cresol)
Cristobalite, see Silica, crystalline									
Crocidolite, see Asbestos									
Crotonaldehyde ^(d)	2	5.7	—	—	—	—	—	—	17 (trans)
Crufomate ^(a)	—	5	—	—	—	—	—	—	
Cumene	SK 50	246	—	—	SK 50	245	75	365	570
Cyanamide	—	2	—	—	—	2	—	—	
Cyanides as CN	SK —	5	—	—	SK —	5 ^(m)	—	—	
Cyanogen	10	21	—	—	10 ⁽ⁿ⁾	20 ⁽ⁿ⁾	—	—	
Cyanogen chloride	0.3 C	0.75 C	—	—	—	—	0.3	0.6	
Cyclohexane	300	1030	—	—	300	1050	375	1300	25
Cyclohexanol	SK 50	206	—	—	50	200	—	—	0.15
Cyclohexanone	SK 25	100	—	—	25	100	100	400	0.88
Cyclohexene	300	1010	—	—	300	1015	—	—	0.18
Cyclohexylamine	10	41	—	—	SK 10	40	—	—	2.6
Cyclonite ^(a)	SK —	1.5	—	—	SK —	1.5	—	3	
Cyclopentadiene	75	203	—	—	—	—	—	—	1.9
Cyclopentane	600	1720	—	—	—	—	—	—	
Cyhexatin	—	5	—	—	—	5	—	10	
2,4-D	—	10	—	—	—	10	—	20	
DDT (Dichloro-diphenyltrichloroethane) ^(f,e)	—	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	360	0.28
Dialkyl 79 phthalate	—	—	—	—	—	5	—	—	
Diallyl phthalate	—	—	—	—	—	5	—	—	
2,2'-Diaminodiethylamine	—	—	—	—	SK 1	4	—	—	
1,2-Diaminoethane, see Ethylenediamine									
Diammonium peroxydisulphate as 5 ₂ O ₈	—	—	—	—	—	1	—	—	
Diatomaceous earth, see Silica, amorphous									
Diazinon ^(k)	SK —	0.1	—	—	SK —	0.1	—	0.3	
Diazomethane ^(d)	0.2	0.34	—	—	UR 0.2	0.4	—	—	
Diborane	0.1	0.11	—	—	0.1	0.1	—	—	2.5
1,2-Dibromoethane, see Ethylene dibromide									
2-N-Dibutylamino-ethanol	SK 2	14	—	—	—	—	—	—	
Dibutyl phenyl phosphate ^(h)	SK 0.3	3.5	—	—	—	—	—	—	
Dibutyl phosphate	1	8.6	2	17	1	5	2	10	
Dibutyl phthalate	—	5	—	—	—	5	—	10	
6,6'-Di-tert-butyl-4,4'-thiodi-m-cresol	—	—	—	—	—	10	—	20	
Dichloroacetylene ^(d)	0.1 C	0.39 C	—	—	—	—	0.1	0.4	
o-Dichlorobenzene	SK 50 C	301 C	—	—	—	—	50	300	0.30
p-Dichlorobenzene	75	451	110	661	75	450	110	675	0.18
3,3'-Dichlorobenzidine ^(d)	—	(g)	—	—	—	—	—	—	
Dichlorodifluoromethane	SK 1000	4950	—	—	1000	4950	1250	6200	

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
1,3-Dichloro-5,5-dimethyl hydantoin	—	0.2	—	0.4	—	0.2	—	0.4	
1,1-Dichloroethane ^(e)	200	810	250	1010	200	810	400	1620	
1,2-Dichloroethane, see Ethylene dichloride									
1,1-Dichloroethylene, see Vinylidene chloride									
1,2-Dichloroethylene	200	793	—	—	200	790	250	1000	17 (trans)
Dichloroethyl ether	SK 5	29	10	58	10	40	—	—	0.049
Dichlorodifluoromethane	10	42	—	—					
Dichloromethane, see Methylene chloride									
1,1-Dichloro-1-nitroethane	2	12	—	—	—	—	—	—	
2,2'-Dichloro-4,4'-niethylene dianiline	—	—	—	—	SK —	0.005 MEL	—	—	
Dichlorophenoxyacetic acid, see 2,4-D									
1,2-Dichloropropane, see Propylene dichloride									
Dichloropropene ^(d)	SK 1	4.5	—	—	SK UR 1	5	10	50	
2,2-Dichloropropionic acid	1	5.8	—	—	—	—	—	—	
Dichlorotetrafluoro-ethane	1000	6990	—	—	1000	7000	1250	8750	
Dichlorvos ^(k)	SK 0.1	0.90	—	—	SK 0.1	1	0.3	3	
Dicrotophos	SK —	0.25	—	—	—	—	—	—	
Dicyclohexyl phthalate	—	—	—	—	—	5	—	—	
Dicyclopentadiene	5	27	—	—	5	30	—	—	0.0057
Dicyclopentadienyl iron	—	10	—	—	—	10	—	20	
Dieldrin ^{(l),(v)}	SK —	0.25	—	—	SK —	0.25	—	0.75	
Diethanolamine	3	13	—	—	3	15	—	—	0.27
Diethylamine	10	30	25	75	10	30	25	75	0.13
2-Diethylamino-ethanol	SK 10	48	—	—	SK 10	50	—	—	0.011
Diethylene glycol	—	—	—	—	23	100	—	—	
Diethylene triamine	SK 1	4.2	—	—	SK 1	4	—	—	
Diethyl ether, see Ethyl ether									
Di(2-ethylhexyl)phthalate, see Di-sec-octyl phthalate									
Diethyl ketone	200	705	—	—	200	700	250	875	2.0
Diethyl phthalate	—	5	—	—	—	5	—	10	
Difluorodibromomethane	100	858	—	—	100	860	150	1290	
Diglycidyl ether (DGE) ^(h)	0.1	0.53	—	—	0.1	0.6	—	—	
Dihydroxybenzene, see Hydroquinone									
Diisobutyl ketone	25	145	—	—	25	150	—	—	0.11
Diisooctyl phthalate	—	—	—	—	—	5	—	—	
Diisodecyl phthalate	—	—	—	—	—	5	—	—	
Diisononyl phthalate	—	—	—	—	—	5	—	—	
Diisopropyl ether	—	—	—	—	250	1050	310	1320	
Diisopropylamine	SK 5	21	—	—	SK 5	20	—	—	1.8
Di-linear 79 phthalate	—	—	—	—	—	5	—	—	
Dimethoxymethane, see Methylal									
Dimethyl acetamide	SK 10	36	—	—	SK 10	35	15	30	47
Dimethylamine	10	18	—	—	10	18	—	—	0.34
Dimethylaminobenzene, see Xylidene									
Dimethylaniline ^(k) (N,N-Dimethylaniline)	SK 5	25	10	50	SK 5	25	10	50	0.013
Dimethylbenzene, see Xylene									
1,3-Dimethylbutyl acetate	—	—	—	—	50	300	100	600	
Dimethyl carbamoyl chloride	(g)	(g)	—	—	—	—	—	—	
Dimethyl-1,2-dibromo-2,2-dichloroethyl phosphate, see Naled									
N,N-Dimethylethylamine	—	—	—	—	10	30	15	45	
Dimethylformamide ^(k)	SK 10	30	—	—	SK 10	30	20	60	2.2
2,6-Dimethyl-4-heptanone, see Diisobutyl ketone									
1,1-Dimethyl hydrazine ^{(d),(v),(n)}	SK (0.5) ^(j)	(1.2) ^(j)	—	—	—	—	—	—	1.7
Dimethylnitrosoamine, see N-Nitrosodimethylamine									
Dimethylphthalate	—	5	—	—	—	5	—	10	
Dimethyl sulphate ^(d)	SK 0.1 ^(v)	0.52 ^(v)	—	—	SK UR 0.1	0.5	0.1	0.5	

Table 4.34 Hygiene standards (see key and notes on pages 95–97)

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Dinitolmide	—	5	—	—	—	—	—	—	
Dinitrobenzene ^(k) (all isomers)	SK 0.15	1.0	—	—	SK 0.15	1	0.5	3	
Dinitro- <i>o</i> -cresol	SK —	0.2	—	—	SK —	0.2	—	0.6	
1,2-Dinitroethane, see Ethylene glycol dinitrate									
1,2-Dinitropropane	—	—	—	—	SK 0.2	1.2	0.2	1.2	
3,5-Dinitro- <i>o</i> -toluamide, see Dinitolmide									
Dinitrotoluene ^(d,e,k)	SK —	1.5	—	—	SK UR —	1.5	—	5	
Di-nonyl phthalate	—	—	—	—	—	5	—	—	
Dioxane ^(d,e)	SK 25	90	—	—	SK 25	90	100	360	24
Dioxathion ^(k)	SK —	0.2	—	—	SK —	0.2	—	—	
Diphenyl, see Biphenyl									
Diphenylamine	—	10	—	—	—	10	—	20	
Diphenyl ether (vapour)	—	—	—	—	1	7	—	—	
Diphenylmethane diisocyanate, see Isocyanates; Methylene bisphenyl isocyanate									
Dipotassium peroxydisulphate, as S ₂ O ₈	—	—	—	—	—	1	—	—	
Dipropylene glycol methyl ether	SK 100	606	150	909	—	—	—	—	
Dipropyl ketone	50	233	—	—	—	—	—	—	
Diquat	—	0.5	—	—	—	0.5	—	—	
Di- <i>sec</i> -octyl phthalate ^(d,e)	—	5	—	10	—	5	—	10	
Disodium peroxydisulphate, as S ₂ O ₈	—	—	—	—	—	1	—	—	
Disulfiram	—	2	—	—	—	—	—	—	
Disulfoton	—	0.1	—	—	—	0.1	—	0.3	
2,6-Di- <i>tert</i> -butyl- <i>p</i> -cresol	—	10	—	—	—	10	—	—	
Diuron	—	10	—	—	—	10	—	—	
Divinyl benzene	10	53	—	—	10	50	—	—	
Dusts						(S) 10 (total inhalable dust) 5 (respirable dust)			
Emery	—	10 ^(h)	—	—	{ —		—	—	
Endosulfan	SK —	0.1	—	—	SK —	0.1	—	0.3	
Endrin	SK —	0.1	—	—	SK —	0.1	—	0.3	
Enflurane	75	566	—	—	—	—	—	—	
Enzymes, see Subtilisins									
Epichlorohydrin ^(d,e,m)	SK (2)	(7.6)	—	—	SK UR 2	8	5	20	0.93
EPN	SK —	0.5	—	—	—	—	—	—	
1,2-Epoxy-4-epoxyethyl cyclohexane	—	—	—	—	UR 10	60	—	—	
1,2-Epoxypropane, see Propylene oxide									
2,3-Epoxy-1-propanol, see Glycidol									
2,3-Epoxypropyl isopropyl ether	—	—	—	—	50	240	75	360	
Ethane		(f)				(f)			120 000
Ethanethiol, see Ethyl mercaptan									
Ethanol, see Ethyl alcohol									
Ethanolamine	3	7.5	6	15	3	8	6	15	2.6
Ethion ^(k)	SK —	0.4	—	—	—	—	—	—	
2-Ethoxyethanol ^(e) (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	1400	—	—	3.9
Ethyl acrylate ^(d,h)	5 ^(g)	20 ^(g)	15 ^(g)	61 ^(g)	SK 5	20	15	60	0.0012
Ethyl alcohol	1000	1880	—	—	1000	1900	—	—	84
Ethylamine	10	18	—	—	10	18	—	—	0.95

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Ethyl amyl ketone	25	131	—	—	25	130	—	—	6.0
Ethyl benzene ^(k)	100	434	125	543	100	435	125	545	2.3
Ethyl bromide ^(m)	(200)	(891)	(250)	(1110)	200	890	250	1110	3.1
Ethyl butyl ketone	50	234	—	—	50	230	75	345	—
Ethyl chloride	1000	2640	—	—	1000	2600	1250	3250	4.2
Ethylene	—	(f)	—	—	—	—	—	—	290
Ethylchloroformate	—	—	—	—	1	4.4	—	—	—
Ethylene chlorohydrin	SK 1 C	3.3 C	—	—	SK 1	3	1	3	—
Ethylenediamine	10	25	—	—	10	25	—	—	1.0
Ethylene dibromide ^(h)	SK (g)	(g)	—	—	SK 0.5	4 MEL	—	—	2.5
Ethylene dichloride ^(l, v)	10	40	—	—	UR 10	40	15	60	88
Ethylene glycol, vapour and mist	50 C	127 C	—	—	{	10 particulate 60 vapour	—	125	—
Ethylene glycol dinitrate ⁽ⁿ⁾	SK 0.05	0.31	—	—	SK 0.2	1.2	0.2	1.2	—
Ethylene glycol methyl ether acetate, see 2-Methoxyethyl acetate	—	—	—	—	SK 5	10 MEL	—	—	430
Ethylene oxide ^(h)	1 ^(g)	1.8 ^(g)	—	—	SK UR 0.5	1	—	—	1.5
Ethylene imine ^(d, e)	SK 0.5	0.88	—	—	SK UR 0.5	1	—	—	8.9
Ethyl ether	400	1210	500	1520	400	1200	500	1500	31
Ethyl formate	100	303	—	—	100	300	150	450	—
2-Ethylhexyl chloroformate	—	—	—	—	1	7.9	—	—	—
Ethylidene chloride, see 1,1-Dichloroethane	—	—	—	—	—	—	—	—	0.014
Ethylidene norbornene	5 C	25 C	—	—	—	—	—	—	0.000 76
Ethyl mercaptan	0.5	1.3	—	—	—	—	—	—	1.4
N-Ethylmorpholine	SK 5	24	—	—	SK 5	23	20	95	17
Ethyl silicate	10	85	—	—	10	85	30	255	—
Fenamiphos ^(k)	SK —	0.1	—	—	—	—	—	—	—
Fenchlorphos	—	—	—	—	—	10	—	—	—
Fensulfothion ^(k)	—	0.1	—	—	—	—	—	—	—
Fenthion ^(k)	SK —	0.2	—	—	—	—	—	—	—
Ferbam	—	10	—	—	—	10	—	20	—
Ferrocene	—	—	—	—	—	10	—	20	—
Ferrovanadium dust	—	1	—	3	—	—	—	—	—
Fibrous glass dust ⁽ⁿ⁾	—	10	—	—	—	—	—	—	—
Fluorides as F ^(k)	—	2.5	—	—	—	2.5	—	—	—
Fluorine ^(m)	1	1.6	2	3.1	—	—	1	1.5	0.14
Fluorotrichloromethane, see Trichlorofluoromethane	—	—	—	—	—	—	—	—	—
Fonofos ^(k)	SK —	0.1	—	—	—	—	—	—	—
Formaldehyde ^(d, e, n)	(1) ^(g)	(1.2) ^(g)	(2) ^(g)	(2.5) ^(g)	2	2.5 MEL	2	2.5 MEL	0.83
Formamide	SK 10	18	—	—	20	30	30	45	—
Formic acid ⁽ⁿ⁾	5	9.4	(—)	(—)	5	9	—	—	49
Furfural ^(k)	SK 2	7.9	—	—	SK 2	8	10	40	0.078
Furfuryl alcohol	SK 10	40	15	60	SK 5	20	15	60	8.0
Gasoline ⁽ⁿ⁾	300	890	500	1 480	—	—	—	—	—
Germanium tetrahydride	0.2	0.63	—	—	0.2	0.6	0.6	1.8	—
Glass, fibrous or dust, see Fibrous glass dust	—	—	—	—	—	—	—	—	—
Glutaraldehyde	0.2 C	0.82 C	—	—	—	—	0.2	0.7	—
Glycerin mist	—	10 (total dust/ particulate)	—	—	—	10	—	—	—
Glycidol	25	76	—	—	—	—	—	—	—
Glycol monoethyl ether, see 2-Ethoxyethanol	—	—	—	—	—	—	—	—	—
Glycerol trinitrate	—	—	—	—	SK 0.2	2	0.2	2	—
Grain dust (oat, wheat, barley)	—	4 (total dust/ particulate)	—	—	—	—	—	—	—
Graphite, natural ⁽ⁿ⁾	—	(2.5) (total dust, particulate, respirable)	—	—	{	10 (total inhalable dust) 5 (respirable dust)	—	—	—
Graphite, synthetic ⁽ⁿ⁾	—	10 ⁽ⁿ⁾	—	—	—	—	—	—	—

Table 4.34 cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	(ppm) ^(a)	STEL (mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Gypsum, see Calcium sulphate	—	0.5	—	—	—	0.5	—	1.5	
Halothane	50	404	—	—	—	—	—	—	33
Helium	—	(f)	—	—	—	(f)	—	—	
Heptachlor ^(d,n)	SK	(0.5)	—	—	SK UR	0.5	—	2	
Heptane (n-Heptane)	400	1640	500	2050	400	1600	500	2000	150
2-Heptanone, see Methyl n-amyl ketone									
3-Heptanone, see Ethyl butyl ketone									
Hexachlorobutadiene	SK	0.02 ^(k)	0.21 ^(k)	—	—	—	—	—	
Hexachlorocyclohexane, see Lindane									
Hexachlorocyclo-pentadiene	0.01	0.11	—	—					0.030 0.15
Hexachloroethane ⁽ⁿ⁾	(1)	(9.7)	—	—		5 50 (vapour) 10 (total inhalable dust) 5 (respirable dust)	—	—	
Hexachloronaphthalene	SK	—	0.2	—	—	—	—	—	
Hexafluoroacetone	SK	0.1	0.68	—	—	—	—	—	
Hexahydro-1,3,5-trinitro-1,3,5-triazine	—	—	—	—	SK	1.5	—	3	
Hexamethylene diisocyanate	0.005	0.034	—	—	see Isocyanates				
Hexamethyl phosphoramidate	SK	(g)	(g)	—	—	—	—	—	
Hexane (n-Hexane) ^(k)	50	176	—	—	20	70	—	—	130
Other isomers ^(v)	500	1760	1000	3500	500	1800	1000	3600	
1,6-Hexanolactam dust	—	—	—	—	—	1	—	3	
vapour	—	—	—	—	5	20	10	40	
2-Hexanone, see Methyl n-butyl ketone									
Hexone, see Methyl isobutyl ketone									
sec-Hexyl acetate	50	295	—	—	SK	50	205	75	300
Hexylene glycol	25 C	121 C	—	—	25	125	25	125	50
Hydrazine ^(d,e,n)	SK	(0.1) ^(k)	(0.13) ^(k)	—	SK UR	0.1	0.1	—	3.7
Hydrazoic acid, vapour	—	—	—	—	—	—	0.1	—	
Hydrogen	—	(f)	—	—	—	(f)	—	—	
Hydrogenated terphenyls	0.5	4.9	—	—	—	—	—	—	
Hydrogen bromide	3 C	9.9 C	—	—	—	—	3	10	2.0
Hydrogen chloride	5 C	7.5 C	—	—	—	—	5	7	0.77
Hydrogen cyanide ^(v)	SK	10 C	11 C	—	SK	—	10	10 MEL	0.58
Hydrogen fluoride as F	3 C	2.6 C	—	—	—	—	3	2.5	0.042
Hydrogen peroxide	1	1.4	—	—	1	1.5	2	3	0.30
Hydrogen selenide as Se	0.05	0.16	—	—	0.05	0.2	—	—	0.0081
Hydrogen sulphide ^(v)	10	14	15	21	10	14	15	21	
Hydroquinone	—	2	—	—	—	2	—	4	
4-Hydroxy-4-methyl-2-pentanone, see Diacetone alcohol									
2-Hydroxypropyl acrylate	0.5	2.8	—	—	SK	0.5	3	—	
Indene	10	48	—	—	10	45	15	70	0.015
Indium and compounds as In	—	0.1	—	—	—	0.1	—	0.3	
Iodine	0.1 C	1.0 C	—	—	—	—	0.1	1	
Iodoform	0.6	10	—	—	0.6	10	1	20	0.005
Iron oxide fume (Fe ₂ O ₃) as Fe	(t)	5	—	—	—	5	—	10	
Iron pentacarbonyl as Fe	0.1	0.23	0.2	0.45	0.01	0.08	—	—	

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(a)	STEL (ppm) ^(a)	(mg/m ³) ^(a)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Iron salts, soluble, as Fe	—	1	—	—	—	1	—	2	
Isoamyl acetate	100	532	—	—	100	525	125	655	0.025
Isoamyl alcohol	100	361	125	452	100	360	125	450	0.042
Isobutyl acetate ^(a)	150	713	—	—	150	700	187	875	0.64
Isobutyl alcohol	SK 50	152	—	—	50	150	75	225	1.6
Isocyanates, all, as-NCO	—	—	—	—	SK	0.02 MEL	—	0.07 MEL	
Isooctyl alcohol	SK 50	266	—	—	50	270	—	—	
Isopentyl acetate	—	—	—	—	100	525	125	655	
Isophorone	5 C	28 C	—	—	—	—	5	25	0.20
Isophorone diisocyanate	SK 0.005	0.045	—	—	see Isocyanates	—	—	—	
Isopropoxyethanol	25	106	—	—	—	—	—	—	
Isopropyl acetate	250	1040	310	1290	—	—	200	840	2.7
Isopropyl alcohol	400	983	500	1230	SK 400	980	500	1225	22
Isopropylamine	5	12	10	24	—	—	—	—	1.2
N-Isopropylaniline	SK 2	11	—	—	—	—	—	—	
Isopropyl chloroformate	—	—	—	—	1	5	—	—	
Isopropyl ether	250	1040	310	1300	250	1050	310	1320	0.017
Isopropyl glycidyl ether (IGE)	50	218	75	356	50	240	75	360	
Kaolin	—	10 ^(a)	—	—	—	—	—	—	
Ketene	0.5	0.86	1.5	2.6	0.5	0.9	1.5	3	
Lead, inorganic dusts and fumes, as Pb ^(d,e,k)	—	0.15	—	—	—	(u)	—	—	
Lead arsenate as PbHAsO ₄	—	0.15	—	—	—	(u)	—	—	
Lead chromate as Cr ^(d,e,m)	—	(0.05) ^(b)	—	—	—	(u)	—	—	
Limestone, see Calcium carbonate	—	—	—	—	—	—	—	—	
Lindane ^(b)	SK —	0.5	—	—	SK —	0.5	—	1.5	
Lithium hydride	—	0.025	—	—	—	0.025	—	—	
Lithium hydroxide	—	—	—	—	—	—	—	1	
LPG (Liquefied petroleum gas)	1000	1800	—	—	1000	1800	1250	2250	
Magnesite	—	10 ^(a)	—	—	{	10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	—	
						5 (fume, respirable dust)	—	10	
						10 (total inhalable dust)	—	—	
Magnesium oxide fume	—	10	—	—	{	10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	—	
						5 (fume, respirable dust)	—	10	
						10 (total inhalable dust)	—	—	
Malathion ^(k)	SK —	10	—	—	SK —	10	—	—	
Maleic anhydride	0.25	1.0	—	—	UR 0.25	1	—	—	0.32
Manganese as Mn	—	—	—	—	—	—	—	—	
Dust and compounds ^(a)	—	5	—	—	—	5	—	—	
Fume	—	1	—	3	—	1	—	3	
Manganese cyclopenta-dienyl tricarbonyl as Mn	SK —	0.1	—	—	SK —	0.1	—	0.3	
Manganese methyl-pentadienyl tricarbonyl	—	—	—	—	SK —	0.2	—	0.6	
Manganese tetroxide	—	—	—	—	—	1	—	—	
Man-made mineral fibre ^(v)	—	—	—	—	—	5 MEL	—	—	
Marble, see Calcium carbonate	—	—	—	—	—	—	—	—	
Mercaptoacetic acid	—	—	—	—	1	5	—	—	
Mercury as Hg	—	—	—	—	—	—	—	—	
Alkyl compounds	SK —	0.01	—	0.03	SK —	0.01	—	0.03	
All forms except alkyl	—	—							
Vapour	—	0.05	—	—	—	0.05	—	0.15	
Aryl and inorganic compounds ^(a)	—	0.1	—	—	—	0.05	—	0.15	
Mesityl oxide ^(a)	15	60	25	100	15	60	25	100	0.45
Methacrylic acid	20	70	—	—	20	70	40	140	
Methacrylonitrile	—	—	—	—	SK 1	3	—	—	
Methane	—	(f)	—	—	—	(f)	—	—	
Methanethiol, see Methyl mercaptan									

Table 4.34 cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	TWA (mg/m ³) ^(b)	STEL (ppm) ^(a)	STEL (mg/m ³) ^(b)	TWA ^(c) (ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (ppm)	STEL ^(c) (mg/m ³)	
Methanol, see Methyl alcohol									
Methomyl ^(k)	—	2.5	—	—	SK —	2.5	—	—	
Methoxychlor	—	10	—	—	—	10	—	—	
2-Methoxyethanol (EGME) ^(a)	SK 5	16	—	—	SK 5	16 MEL	—	—	2.3
2-Methoxyethyl acetate (EGMEA)	SK 5	24	—	—	SK 5	24 MEL	—	—	—
4-Methoxyphenol	—	5	—	—	—	5	—	—	
1-Methoxypropan-2-ol	—	—	—	—	SK 100	360	300	1080	
Methyl acetate	200	606	250	757	200	610	250	760	4.6
Methyl acetylene ^(a)	1000	1640	—	—	—	—	—	—	50
Methyl acetylene-propadiene mixture (MAPP)	1000	1640	1250	2050	—	—	—	—	
Methyl acrylate	SK 10	35	—	—	10	35	—	—	0.0048
Methylacrylonitrile	SK 1	2.7	—	—	—	—	—	—	7.0
Methylal	1000	3110	—	—	1000	3100	1250	3875	
Methyl alcohol	SK 200	262	250	328	SK 200	260	250	310	100
Methylamine	10	13	—	—	10	12	—	—	3.2
Methyl amyl alcohol, see Methyl isobutyl carbinol									
Methyl <i>n</i> -amyl ketone	50	233	—	—	50	240	—	—	0.35
<i>N</i> -Methyl aniline	SK 0.5	2.2	—	—	SK 0.5	2	—	—	1.7
Methyl bromide ^(d,e)	SK 5	19	—	—	SK 5	20	15	60	
3-Methylbutan-1-ol	—	—	—	—	100	360	125	450	
1-Methylbutyl acetate	—	—	—	—	—	—	150	800	
Methyl <i>n</i> -butyl ketone ^(a)	SK 5	20	—	—	SK 5	20	—	—	0.076
Methyl chloride ^(d,e)	SK 50	103	100	207	50	105	100	210	
Methyl chloroform ^(c,k)	350	1910	450	2460	350	1900 MEL	450	2450 MEL	120
Methyl-2-cyanoacrylate	2	9.1	4	18	2	8	4	16	2.2
Methylcyclohexane	400	1610	—	—	400	1600	500	2000	630
Methylcyclohexanol	50	234	—	—	50	235	75	350	500 (cis)
<i>o</i> -Methylcyclohexanone	50	229	75	344	SK 50	230	75	345	
2-Methylcyclopentadienyl manganese tricarbonyl as Mn	SK —	0.2	—	—	SK —	0.2	—	0.6	
Methyl demeton ^(k)	SK —	0.5	—	—	—	—	—	—	
2-Methyl-4,6-dinitrophenol	—	—	—	—	SK —	0.2	—	0.6	
Methylene bisphenyl isocyanate (MDI)	0.005	0.051	—	—	see Isocyanates				
Methylene chloride ^(d,e)	50 ^(g)	174 ^(g)	—	—	SK 100	350 MEL	250	UR 870	250
4,4'-Methylene bis(2-chloroaniline) ^(d,e,k,n)	SK (0.02) ^(g)	(0.22) ^(g)	—	—	—	—	—	—	
Methylene bis(4-cyclohexylisocyanate)	0.005	0.054	—	—	see Isocyanates				
4,4'-Methylenedianiline	SK 0.1 ^(g)	0.81 ^(g)	—	—	UR 0.1	0.8	0.5	4	
Methyl ethyl ketone (MEK) ^(k)	200	590	300	885	200	590	300	885	5.4
Methyl ethyl ketone peroxide	0.2 C	1.5 C	—	—	—	—	0.2	1.5	
Methyl formate	100	246	150	368	100	250	150	375	600
5-Methyl-3-heptanone, see Ethyl amyl ketone									
Methylhexan-2-one	—	—	—	—	50	240	75	360	
Methyl hydrazine ^(d,e,n)	SK (0.2 C) ^(g)	(0.38 C) ^(g)	—	—	—	—	—	—	1.7
Methyl iodide ^(d,e)	SK 2 ^(g)	12 ^(g)	—	—	SK UR 5	28	10	56	
Methyl isoamyl ketone	50	234	—	—	50	240	75	360	0.012
Methyl isobutyl carbinol	SK 25	104	40	167	SK 25	100	40	160	0.070
Methyl isobutyl ketone	50	205	75	307	SK 50	205	75	300	0.68
Methyl isocyanate	SK 0.02	0.047	—	—	see Isocyanates				2.1
Methyl isopropyl ketone	200	705	—	—	—	—	—	—	1.9

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)		
	(ppm) ^(a)	TWA (mg/m ³) ^(a)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)			
Methyl methacrylate	100	410	—	—	100	410	125	510	0.083		
Methyl parathion ^(k)	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	160		
4-Methylpentan-2-one	—	—	—	—	SK	50	205	75	300		
4-Methylpent-3-en-2-one	—	—	—	—	15	60	25	100			
2-Methylpropan-1-ol	—	—	—	—	50	150	75	225			
Methyl propyl ketone ^(e)	200	705	250	881	200	700	250	875	11		
1-Methyl-2-pyrrolidone	—	—	—	—	100	400	—	—			
Methyl silicate	1	6	—	—	1	6	5	30			
Methyl styrene (all isomers except α-methyl styrene)	—	—	—	—	100	480	150	720			
α-Methyl styrene	50	242	100	483	—	—	100	480	0.29		
N-Methyl-N,2,4,6-tetranitroaniline	—	—	—	—	—	1.5	—	3			
Metribuzin	—	5	—	—	—	—	—	—			
Mevinphos ^(k)	SK	0.01	0.092	0.03	0.27	SK	0.01	0.03	0.3		
Mica	—	3	—	—	{	—	10 (total inhalable dust)	—			
		(respirable dust)				—	1 (respirable dust) (v)	—			
Mineral wool fibre	—	10 ^(a)	—	—							
Molybdenum as Mo											
Soluble compounds	—	5	—	—	—	5	—	10			
Insoluble compounds	—	10	—	—	—	10	—	20			
Monochloroacetic acid	—	—	—	—	SK	0.3	1	—			
Monochlorobenzene, see Chlorobenzene											
Monocrotophos	—	0.25	—	—	—	—	—	—			
Morpholine ⁽ⁿ⁾	SK	20	71	(30)	(107)	SK	20	70	30	105	0.01
Naled ^(k)	SK	—	3	—	—	—	3	—	6		
Naphthalene	10	52	15	79	10	50	15	75	0.084		
β-Naphthylamine ^(d)		(j)									
Neon		(f)					(f)				
Nickel											
Metal ^(m)	—	(1)	—	—	UR PR	—	0.5	—	—		
Insoluble compounds as Ni ⁽ⁿ⁾	—	(1)	—	—	UR PR	—	0.5	—	—		
Soluble compounds as Ni ^(d,e,n)	—	(0.1)	—	—	UR PR	—	0.1	—	—		
						(inorganic)					
Nickel carbonyl as Ni ^(d,e,n)	(0.05)	(0.35)	—	—	—	—	0.1	0.24	0.30		
Nickel organic compounds as Ni	—	—	—	—	—	1	—	3			
Nickel sulphide roasting, fume and dust, as Ni ^(d,e,n)	—	(1) ^(b)	—	—	—	—	—	—			
Nicotine	SK	—	0.5	—	SK	—	0.5	—	1.5		
Nitrapyrin	—	10	—	20	—	10	—	20			
Nitric acid	2	5.2	4	10	2	5	4	10			
Nitric oxide ^(k)	25	31	—	—	25	30	35	45			
p-Nitroaniline ^(k)	SK	—	3	—	SK	—	6	—	—		
Nitrobenzene ^(k)	SK	1	5	—	SK	1	5	2	10	0.018	
p-Nitrochlorobenzene ^(k)	SK	0.1	0.64	—	—	—	—	—	—		
4-Nitrodiphenyl ^(d)		(j)									
Nitroethane	100	307	—	—	100	310	—	—	2.1		
Nitrogen		(f)				(f)					
Nitrogen dioxide ⁽ⁿ⁾	3	5.6	5	9.4	3	5	5	9	0.39		
Nitrogen trifluoride ^(k)	10	29	—	—	10	30	15	45			
Nitroglycerin (NG)	SK	0.05	0.46	—	SK	0.2	2	0.2	2		
Nitromethane ⁽ⁿ⁾	(100)	(250)	—	—	100	250	150	375	3.5		
1-Nitropropane	25	91	—	—	25	90	—	—	11.0		
2-Nitropropane ^(d)	10 ^(k)	36 ^(k)	—	—	UR	10	36	20	72	70	
N-Nitrosodimethylamine ^(d)	SK	—	(g)	—	—	—	—	—	—		
Nitrotoluene ^(k)	SK	2	11	—	SK	5	30	10	60	0.045	

Table 4.34 cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	(ppm) ^(a)	STEL (mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	(ppm)	STEL ^(c) (mg/m ³)	
Nitrotrichloromethane, see Chloropicrin									
Nitrous oxide	50	90	—	—	—	—	—	—	
Nonane	200	1050	—	—	—	—	—	—	47
Nuisance particulates, see Particulates not otherwise classified (PNOC); Dusts									
Octachloronaphthalene	SK	0.1	—	0.3	SK	0.1	—	0.3	
Octane	300	1400	375	1750	300	1450	375	1800	48
Oil mist, mineral	—	5 ^(w)	—	10	—	5	—	10	
Osmium tetroxide as Os	0.0002	0.0016	0.0006	0.0047	0.0002	0.002	0.0006	0.006	0.0019
Oxalic acid	—	1	—	2	—	1	—	2	
Oxydiethanol	—	—	—	—	23	100	—	—	
Oxygen difluoride	0.05 C	0.11 C	—	—	—	—	—	—	0.10
Ozone	0.1 C	0.20 C	—	—	0.1	0.2	0.3	0.6	0.045
Paraffin wax fume	—	2	—	—	—	2	—	6	
Paraquat, respirable sizes	—	0.1	—	—	—	0.1	—	—	
Parathion ^(e,k)	SK	0.1	—	—	SK	0.1	—	0.3	
Parathion-methyl	—	—	—	—	SK	0.2	—	0.6	
Particulate polycyclic aromatic hydrocarbons (PPAH), see Coal tar pitch volatiles									
Particulates not otherwise classified (PNOC)	—	10 ^(b)	—	—	see Dusts				
Pentaborane	0.005	0.013	0.015	0.039	—	—	—	—	0.96
Pentachloronaphthalene	—	0.5	—	—	—	—	—	—	
Pentachlorophenol ^(k)	SK	0.5	—	—	SK	0.5	—	1.5	
Pentaerythritol	—	10	—	—	—	10 (total inhalable dust)	—	20	
					—	5 (respirable dust)	—	—	
Pentane ^(w)	600	1770	750	2210	600	1800	750	2250	400
2-Pentanone, see Methyl propyl ketone									
Pentyl acetate	—	—	—	—	100	530	150	800	
Perchloroethylene ^(d,e,k)	50	339	200	1357	50	335	150	1000	27
Perchloromethyl mercaptan	0.1	0.76	—	—	—	—	—	—	
Perchloryl fluoride	3	13	6	25	3	14	6	28	
Precipitated silica, see Silica, amorphous									
Perlite	—	10 ^(b)	—	—	—	—	—	—	
Petroleum distillates, see Gasoline; Stoddard solvent; VM&P naphtha									
Phenacyl chloride, see α -Chloroacetophenone									
Phenol ^(k)	SK	5	19	—	SK	5	19	38	0.040
Phenothiazine	SK	5	—	—	—	—	—	—	
N-Phenyl- β -naphthylamine	(g)	(g)	—	—	—	—	—	—	
p-Phenylenediamine	SK	0.1	—	—	SK	0.1	—	—	
Phenyl-2,3-epoxypropyl ether	—	—	—	—	1	6	—	—	
Phenyl ether vapour	1	7	2	14	—	—	—	—	0.0012
Phenylethylene, see Styrene, monomer									
Phenyl glycidyl ether (PGE) ^(d,e)	1	6.1	—	—	—	—	—	—	
Phenylhydrazine ^(d,e,n)	SK	(5) ^(d)	22 ^(d)	10 ^(d)	SK	5	20	45	
Phenyl mercaptan ^(e)	0.5	2.3	—	—	—	—	—	—	0.000 94
Phenylphosphine	0.05 C	0.23 C	—	—	—	—	—	—	
Phorate	SK	0.05	—	0.2	SK	0.05	—	0.2	
Phosdrin, see Mevinphos									
Phosgene	0.1	0.40	—	—	0.1	0.4	—	—	0.90
Phosphine	0.3	0.42	1	14	—	—	0.3	0.4	0.51
Phosphoric acid	—	1	—	3	—	1	—	3	

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(c) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Phosphorus (yellow)	—	0.1	—	—	—	0.1	—	0.3	
Phosphorus oxychloride ^(a)	0.1	0.63	—	—	0.2	1.2	0.6	3.6	
Phosphorus pentachloride	0.1	0.85	—	—	0.1	1	—	—	
Phosphorus pentasulphide	—	1	—	3	—	1	—	3	
Phosphorus trichloride	0.2	1.1	0.5	2.8	0.2	1.5	0.5	3	
Phthalic anhydride	1	6.1	—	—	SEN UR 1	6	4	24	0.053
m-Phthalodinitrile	—	5	—	—	—	—	—	—	
Picloram ^(a)	—	10	—	—	—	10	—	20	
Picric acid ^(b)	—	0.1	—	—	SK —	0.1	—	0.3	
Pindone	—	0.1	—	—	—	—	—	—	
Piperazine dihydrochloride	—	5	—	—	—	5	—	—	
Piperidine	—	—	—	—	SK 1	3.5	—	—	
2-Privalyl-1,3-indandione, see Pindone									
Plaster of Paris, see Calcium sulphate									
Platinum									
Metal	—	1	—	—	—	5	—	—	
Soluble salts, as Pt	—	0.002	—	—	—	0.002	—	—	
Polychlorobiphenyls, see Chlorodiphenyls									
Polytetrafluoroethylene decomposition products		(x)							
Polyvinyl chloride									
Total inhalable dust	—	—	—	—	—	10	—	—	
Respirable dust	—	—	—	—	—	5	—	—	
Portland cement	—	10 ⁽ⁿ⁾	—	—	—	—	—	—	
Potassium hydroxide	—	2 C	—	—	—	—	—	2	
Propane	—	(f)	—	—	—	—	—	—	16 000
Propane-1,2-diol									
Total (vapour + particulates)	—	—	—	—	150	470	—	—	
Particulates	—	—	—	—	—	10	—	—	
Propane sulfone	(g)	(g)							
Propargyl alcohol	SK 1	2.3	—	—	SK 1	2	3	6	
β-Propiolactone ^(d)	0.5 ^(k)	1.5 ^(k)	—	—	—	—	—	—	
Propionic acid ^(a)	10	30	—	—	10	30	15	45	0.16
Propoxur	—	0.5	—	—	—	0.5	—	2	
n-Propyl acetate	200	835	250	1040	200	840	250	1050	0.67
n-Propyl alcohol	SK 200	492	250	614	SK 200	500	250	625	2.6
Propylene	—	(f)	—	—	—	—	—	—	76
Propylene dichloride	75	347	110	508	—	—	—	—	0.25
Propylene glycol dinitrate	SK 0.5	0.34	—	—	SK 0.2	1.2	0.2	1.2	
Propylene glycol monomethyl ether	100	369	150	553	SK 100	360	300	1080	10
Propylene imine ^(b)	SK 2 ^(k)	4.7 ^(k)	—	—	—	—	—	—	
Propylene oxide ^(b)	20	48	—	—	20	50	100	240	44
n-Propyl nitrate ^(k)	25	107	40	172	—	—	—	—	
Propyne, see Methyl acetylene									
Prop-2-yn-1-ol	—	—	—	—	SK 1	2	3	6	
Pyrethrins	—	—	—	—	—	5	—	10	
Pyrethrum	—	5	—	—	—	—	—	—	
2-Pyridylamine	—	—	—	—	0.5	2	2	8	
Pyridine	5	16	—	—	5	15	10	30	0.17
Pyrocatechol, see Catechol									
Quartz, see Silica, crystalline									
Quinone	0.1	0.44	—	—	0.1	0.4	0.3	1.2	0.084
RDX, see Cyclonite									
Resorcinol	10	45	20	90	10	45	20	90	
Rhodium ^(a)									
Metal	—	1	—	—	—	0.1 (Fume and dust)	—	0.3	
Insoluble compounds as Rh	—	1	—	—	—	—	—	—	
Soluble compounds as Rh	—	0.01	—	—	—	0.001	—	0.003	

Table 4.34 cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(a) (ppm)	(mg/m ³)	STEL ^(a) (ppm)	(mg/m ³)	
Ronnel	—	10	—	—	—	10	—	—	
Rosin core solder, pyrolysis products as formaldehyde	—	0.1	—	—	SEN	0.1	—	0.3	
Rotenone (commercial)	—	5	—	—	—	5	—	10	
Rouge	—	10 ^(a)	—	—	{	10 (total inhalable dust)	—	—	
Rubber fume	—	—	—	—		5 (respirable dust)	—	—	
Rubber process dust	—	—	—	—	—	0.6 MEL	—	—	
Rubber solvent (naphtha)	400	1590	—	—	—	8 MEL	—	—	
Selenium and compounds as Se	—	0.2	—	—	—	0.1 (except hydrogen selenide)	—	—	
Selenium hexafluoride as Se	0.05	0.16	—	—	—	—	—	—	
Sesone	—	10	—	—	—	10	—	20	
Silane, see Silicon tetrahydride									
Silica, Amorphous					0.5	0.7	1	1.5	
Diatomaceous earth ^(c)	—	10 ^(a) (uncalcined)	—	—	—	1.5 (natural respirable)	—	—	
Precipitated silica ^(c)	—	10 ^(a)	—	—	{	6 (total inhalable dust)	—	—	
Silica gel ^(c)	—	10 ^(a)	—	—		3 (respirable dust)	—	—	
Silica, Crystalline									
Cristobalite	—	0.05 (respirable dust)	—	—	{	—	—	—	
Quartz	—	0.1 (respirable dust)	—	—		0.4 MEL (respirable dust)	—	—	
Silica, fused ^(c, m)	—	(0.1) (respirable dust)	—	—	{	—	—	—	
Tridymite	—	0.05 (respirable dust)	—	—		0.1 (respirable dust)	—	—	
Tripoli		0.1 (of contained respirable quartz)			—	—	—	—	
						0.1 (respirable dust)			
Silicon	—	10 ^(a)	—	—	{	10 (total inhalable dust)	—	—	
Silicon carbide	—	10 ^(a)	—	—		5 (respirable dust)	—	—	
Silicon tetrahydride	5	6.6	—	—	{	10 (total inhalable dust)	—	—	
Silver	—	0.1	—	—		5 (respirable dust)	—	—	
Metal ^(c)	—	0.01	—	—	0.5	0.7	1	1.5	
Soluble compounds as Ag	—	0.01	—	—	UR	0.1	—	—	
						0.01	—	—	

Table 4.34 Cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Soapstone									
Respirable dust	—	3	—	—	—	—	—	—	
Total dust	—	6 ^(b)	—	—	—	—	—	—	
Sodium azide	0.11 C	0.29 C	—	—	—	—	—	—	0.3
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	—	2 C	—	—	—	—	—	2	
Sodium metabisulphite	—	5	—	—	—	5	—	—	
Starch	—	10	—	—	{	10 (total inhalable dust)	—	—	
						5 (respirable dust)	—	—	
Stearates ^(v)	—	10	—	—	—	—	—	—	
Stibine	0.1	0.51	—	—	0.1	0.5	0.3	1.5	
Stoddard solvent ^(a)	100	525	—	—	—	—	—	—	
Strychnine	—	0.15	—	—	—	0.15	—	0.45	
Styrene, monomer ^{(d),(k)}	SK 50	213	100	426	100	420 MEL	250	1050 MEL	0.32
Subtilisins (proteolytic enzymes as 1 (G)% pure crystalline enzyme)	—	0.000 06 C ^(r)	—	—	—	0.000 06	—	0.000 06	
Sucrose	—	10	—	—	—	10	—	20	
Sulfatep ^(k)	SK —	0.2	—	—	SK —	0.2	—	—	
Sulphur dioxide	2	5.2	5	13	2	5	5	13	1.1
Sulphur hexafluoride	1000	5970	—	—	1000	6000	1250	7500	
Sulphuric acid	—	1	—	3	—	1	—	—	
Sulphur monochloride	1 C	5.5 C	—	—	1	6	3	18	
Sulphur pentafluoride	0.01 C	0.10 C	—	—	0.025	0.25	0.075	0.75	
Sulphur tetrafluoride	0.1 C	0.44 C	—	—	0.1	0.4	0.3	1	
Sulphuryl fluoride	5	21	10	42	5	20	10	40	
Sulprofos	—	1	—	—	—	—	—	—	
Systox, see Demeton									
2,4,5-T	—	10	—	—	—	10	—	20	
Talc (containing no asbestos fibres)	—	2 (respirable dust)	—	—	{	10 (total inhalable dust)	—	—	
						1 (respirable dust)	—	—	
Talc (containing asbestos fibres) ^(d)		Use asbestos TLV-TWA ^{(a),(b)}							
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 ^(k)	—	10	—	—	—	—	—	—	
TEPP ^(k)	SK 0.004	0.047	—	—	SK 0.004	0.05	0.01	0.2	
Terphenyls	0.5 C	4.7 C	—	—	—	—	0.5	5	
1,1,2,2-Tetrabromoethane	—	—	—	—	SK 0.5	7	—	—	
1,1,1,2-Tetrachloro-2,2-difluoroethane	500	4170	—	—	100	834	100	834	
1,1,2,2-Tetrachloro-1,2-difluoroethane	500	4170	—	—	100	834	100	834	
1,1,2,2-Tetrachloroethane ^(d)	SK 1	6.9	—	—	—	—	—	—	1.5
Tetrachloroethylene, see Perchloroethylene									
Tetrachloromethane, see Carbon tetrachloride									
Tetrachloronaphthalene	—	2	—	—	—	2	—	4	
Tetraethyl lead as Pb ^(v)	SK —	0.1 ^{(b),(h)}	—	—	—	—	—	—	
Tetraethyl orthosilicate	—	—	—	—	10	85	30	255	
Tetrahydrofuran	200	590	250	737	200	590	250	735	2.0

Table 4.34 cont'd

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)
	TWA (ppm) ^(a)	(mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	TWA ^(a) (ppm)	(mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)	
Tetramethyl lead as Pb ^(a)	SK —	0.15 ^(b)	—	—	—	—	—	—	
Tetramethyl orthosilicate	—	—	—	—	1	6	5	30	
Tetramethyl succinonitrile	SK 0.5	2.8	—	—	SK 0.5	3	2	9	
Tetranitromethane	1	8	—	—	—	—	—	—	
Tetrasodium pyrophosphate	—	5	—	—	—	5	—	—	
Tetryl ^(a)	—	1.5	—	—	SK —	1.5	—	3	
Thallium, soluble compounds, as Tl	SK —	0.1	—	—	SK —	0.1	—	—	
4,4'-Thiobis(6-tert-butyl-m-cresol)	—	10	—	—	—	10	—	20	
Thioglycolic acid	SK 1	3.8	—	—	1	5	—	—	
Thionyl chloride	1 C	4.9 C	—	—	—	—	1	5	
Thiram ^(b)	—	1	—	—	—	5	—	10	
Tin									
Metal	—	2	—	—	—	—	—	—	
Oxide and organic compounds except SnH ₄ , as Sn	—	2	—	—	—	2	—	4	
Organic compounds as Sn ^(a)	SK —	0.1	—	(—)	SK —	0.1 (except Cyhexin)	—	0.2	
						10 (total inhalable dust)	—	—	
Titanium dioxide	—	10 ^(a)	—	—	—	5 (respirable dust)	—	—	
<i>o</i> -Tolidine ^(d)	SK (g)	(g)							
Toluene ^(k)	100	377	150	565	SK 50	188	150	560	2.9
Toluene-2,4-diisocyanate (TDI)	0.005	0.036	0.02	0.14	see Isocyanates				
<i>p</i> -Toluenesulphonyl chloride	—	—	—	—	—	—	—	5	0.17
<i>o</i> -Toluidine ^{(l),(k)}	SK 2 ^(k)	8.8 ^(k)	—	—	2	9	5	22	0.25
<i>m</i> -Toluidine ^(k)	SK 2	8.8	—	—	—	—	—	—	
<i>p</i> -Toluidine ^{(l),(k)}	SK 2 ^(k)	8.8 ^(k)	—	—	—	—	—	—	
Toluol, see Toluene									
Toxaphene, see Chlorinated camphene									
Tributyl phosphate	0.2	2.2	—	—	—	5	—	5	
Trichloroacetic acid	1	6.7	—	—	UR 1	5	—	—	
1,2,4-Trichlorobenzene	5 C	37 C	—	—	5	40	5	40	1.4
1,1,1-Trichloroethane, ^{(d),(e)} see Methyl chloroform									
1,1,2-Trichloroethane	SK 10	55	—	—	SK UR 10	45	20	90	
Trichloroethylene ^{(d),(e),(k)}	50	269	200	1 070	SK 100	535 MEL	150	802 MEL	28
Trichlorofluoromethane	1000 C	5620 C	—	—	1000	5600	1250	7000	5
Trichloromethane, see Chloroform									
Trichloronaphthalene	SK —	5	—	—	—	—	—	—	
Trichloronitromethane, see Chloropicrin									
1,2,3-Trichloropropane	SK 10	60	—	—	50	300	75	450	
1,1,2-Trichloro-1,2,2-trifluoroethane	1000	7670	1 250	9590	1000	7600	1250	9500	45
Tricyclohexyltin hydroxide, see Cyhexatin									
Tridymite, see Silica, crystalline									
Triethylamine	10	41	15	62	10	40	15	60	0.48
Trifluorobromomethane	1000	6090	—	—	1000	6100	1200	7300	
Trimellitic anhydride	0.005	0.039	—	—	—	0.04	—	—	
Trimethylamine	10	24	15	36	10	24	15	36	0.000 44
Trimethyl benzene	25	123	—	—	UR 25	125	35	170	0.55
3,5,5-Trimethylcyclohex-2-enone	—	—	—	—	—	—	5	25	
Trimethyl phosphite	2	10	—	—	2	10	—	—	0.000 10
2,4,6-Trinitrophenol, see Picric acid									
2,4,6-Trinitrophenylmethyl nitramine, see Tetryl									
2,4,6-Trinitrotoluene (TNT) ^{(d),(k)}	SK —	0.5	—	—	—	0.5	—	0.5	

Substance	Threshold limit values (USA)				Occupational exposure limits (UK)				Air odour threshold (ppm; v/v)	
	(ppm) ^(a)	TWA (mg/m ³) ^(b)	STEL (ppm) ^(a)	(mg/m ³) ^(b)	(ppm)	TWA ^(c) (mg/m ³)	STEL ^(c) (ppm)	(mg/m ³)		
Inorthocresyl phosphate	SK	—	0.1	—	—	0.1	—	0.3		
Tri-o-tolyl phosphate	—	—	—	—	—	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	556	—	—	100	560	150	840		
Uranium (natural) ^(e)										
Soluble and insoluble compounds as U	—	0.2	—	0.6	—	0.2	—	0.6		
n-Valeraldehyde	50	176	—	—	—	—	—	—	0.028	
Vanadium as V ₂ O ₅										
Respirable dust and fume	—	0.05	—	—	{	0.5 (total inhalable dust)	—	—		
						0.05 (Fume and respirable dust)	—	—		
Vegetable oil mists ^(c,c)	—	10	—	—	—	—	—	—		
Vinyl acetate ^(e)	10	35	20	70	10	30	20	60	0.50	
Vinyl benzene, see Styrene										
Vinyl bromide ^(d,e)	5 ^(b)	22 ^(b)	—	—	UR	5	20	—		
Vinyl chloride ^(d,e)	5 ^(b)	13 ^(b)	—	—	7 ^(dd)	— MEL	—	—	3000	
Vinyl cyanide, see Acrylonitrile										
Vinyl cyclohexene dioxide	SK	10 ^(b)	57 ^(b)	—	—	—	—	—		
Vinylidene chloride ^(d,e)	5	20	20	79	UR	10	40 MEL	—	190	
Vinyl toluene	50	242	100	483	—	—	—	—	10	
VM&P naphtha	300	1370	—	—	—	—	—	—		
Warfarin	—	0.1	—	—	—	0.1	—	0.3		
Welding fumes (NOC)	—	5 ^(b)	—	—	—	5	—	—		
White spirit	—	—	—	—	100	575	125	720		
Wood dust (certain hardwoods e.g. beech, oak) ^(d)	—	1	—	—	SEN	5 MEL	—	—		
Softwood ^(d)	—	5	—	10	UR	5	—	—		
Xylene ^(k)										
o-,m-,p-isomers	100	434	150	651	SK	100	435	150	650	1.1 (meta)
m-Xylene α,α'-diamine	SK	—	0.1 C	—	—	—	—	—		
Xylidine, mixed isomers	SK	0.5 ^(b)	2.5 ^(b)	—	SK	2	10	10	50	0.056 (2,4-Xylidine)
Yttrium, metal and compounds, as Y	—	1	—	—	—	1	—	3		
Zinc chloride fume	—	1	—	2	—	1	—	2		
Zinc chromates ^(d,e) as Cr	—	0.01 ^(b)	—	—	—	—	—	—		
Zinc distearate										
Total inhalable dust	—	—	—	—	—	10	—	20		
Respirable dust	—	—	—	—	—	5	—	—		
Zinc oxide										
Fume	—	5	—	10	—	5	—	10		
Dust	—	10 ^(b)	—	—	—	—	—	—		
Zirconium and compounds, as Zr	—	5	—	10	—	5	—	10		

C Ceiling limit

NOC Not otherwise classified

PR Provisional

SEN Capable of causing respiratory sensitization; skin sensitizers have not been given a separate notation

SK Can be absorbed through skin

UR Under review

This table is a useful guide but because standards are continually under review reference should be made to the most recent edition of HSE EH/40 and the AGGIH TLV list for current values.

Table 4.34 cont'd

- (a) Parts of vapour or gas per million parts of contaminated air by volume at 25°C and 760 torr (1.013 bar).
- (b) Milligrams of substance per m³ air.
- (c) Value shown is OES unless otherwise indicated as MEL.
- (d) Substance identified by sources other than TLV as a suspected or confirmed human carcinogen.
- (e) Substance for which the TLV is higher than the OSHA Permissible Exposure Limit (PEL) and/or the NIOSH Recommended Exposure Limit (REL).
- (f) 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.)
- (g) Suspected human carcinogens – see TLV Appendix A, Category A2 (below).
- (h) 1990–1991 adoption.
- (i) The value is for total dust containing no asbestos and <1% crystalline silica.
- (j) Confirmed human carcinogen – see TLV Appendix A, Category A1 (below).
- (k) Substance for which there is also a BEI (see Table 4.35).
- (l) 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.
- (m) UK control limits for asbestos:
- | | |
|-------------------------|---|
| Crocidolite or amosite | 0.2 fibres/ml of air averaged over any continuous 4 hr period |
| | 0.6 fibres/ml of air averaged over any continuous 10 min period |
| Other types of asbestos | 0.5 fibres/ml of air averaged over any continuous 4 hr period |
| | 1.5 fibres/ml of air averaged over any continuous 10 min period |
- Action levels for cumulative exposures within a 12 week period:
- (a) for crocidolite or amosite containing asbestos, 48 fibre hours/ml of air or
- (b) for other types of asbestos, 120 fibre hr/ml of air or
- (c) a proportionate number of fibre hr/ml of air for exposure to both types of asbestos which occur at different times within the 12 week period.
- (n) Adopted values enclosed in parentheses are those for which changes are proposed – consult TLV Notice of Intended Changes for current proposal.
- (o) 1991, TLV-STEL deleted.
- (p) The value is for dust containing <5% silica. For dust containing more than this percentage of free silica, the environment should be evaluated against the TLV-TWA of 0.1 mg/m³ for respirable quartz.
- (q) Lint-free dust as measured by the vertical elutriator cotton-dust sampler described in the *Transactions of the National Conference on Cotton Dust*, p. 33, J.R. Lynch (May 2, 1970).
- (r) Except hydrogen cyanide, cyanogen and cyanogen chloride.
- (s) 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/m³ 8 hr TWA total inhalable dust and 5 mg/m³ 8 hr TWA respirable dust.
- (t) 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^3 . That which does, should be controlled.

(u) The UK lead-in-air standard is:

Lead and lead compounds (except tetraethyl lead)	0.15 mg/m^3 of air
Tetraethyl lead (as lead)	0.10 mg/m^3 of air

Appendix 5 of EH40 should be consulted for provisos.

(v) 'Fibre' means length $> 5 \mu\text{m}$, average diameter $< 3 \mu\text{m}$ and length:dia ratio $> 3:1$.

(w) As sampled by method that does not collect vapour.

(x) 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.)

(y) Does not include stearates of toxic metals.

(z) Based on 'high volume' sampling.

(aa) However, should not exceed 2 mg/m^3 respirable dust.

(bb) For control of general room air, biological monitoring is essential for personnel control.

(cc) Except castor, cashew nut or similar irritant oils.

(dd) In the UK vinyl chloride is also subject to an overriding annual maximum exposure limit of 3 ppm.

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 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 processes, recognized to have carcinogenic potential.
A2 — *Suspected human carcinogens*. Chemical substances, or substances associated with industrial processes, which are suspect of inducing cancer, based on either 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.

Table 4.35 Adopted biological exposure determinants (ACGIH)

<i>Airborne chemical Determinant</i>	<i>Sampling time</i>	<i>BEI</i>	<i>Notes</i>
Benzene			
Total phenol in urine	End of shift	50 mg/l	B, Ns
Benzene in exhaled air:	Prior to next shift		
mixed-exhaled		0.08 ppm	Cf
end-exhaled		0.12 ppm	Cf
Cadmium			
Cadmium in urine	Not critical	10 µg/g creatinine	B
Cadmium in blood	Not critical	10 µg/l	B
Carbon disulphide			
2-Thiothiazolidine-4-carboxylic acid (= TTCA) in urine	End of shift	5 mg/g creatinine	
Chromium (VI), water soluble fume			
Total chromium in urine	Increase during shift	10 µg/g creatinine	B
	End of shift at end of workweek	30 µg/g creatinine	B
Carbon monoxide			Sc
Carboxyhaemoglobin in blood	End of shift	<8% of haemoglobin	B, Ns
CO in end-exhaled air	End of shift	<40 ppm	B, Ns
N,N-Dimethylformamide (DMF)			
N-Methylformamide in urine	End of shift	40 mg/g creatinine	
Ethyl benzene			
Mandelic acid in urine	End of shift at end of workweek	2 g/l	Ns
		1.5 g/g creatinine	
Ethyl benzene in end-exhaled air	Prior to next shift	2 ppm	Cf
Fluorides			
Fluorides in urine	Prior to shift	3 mg/l	B, Ns
	End of shift	10 mg/l	B, Ns
n-Hexane			
2,5-Hexanedione in urine	End of shift	5 mg/l	Ns
n-Hexane in end-exhaled air	During shift	40 ppm	Cf
Lead			Sc
Lead in blood	Not critical	50 µg/100 ml	B
Lead in urine	Not critical	150 µg/g creatinine	B
Zinc protoporphyrin in blood	After 1 month exposure	250 µg/100 ml erythrocytes or 100 µg/100 ml blood	B
Methemoglobin inducers			
Methemoglobin in blood	During or end of shift	1.5% of haemoglobin	B, Ns, Cf
Methyl chloroform			
Methyl chloroform in end-exhaled air	Prior to the last shift of workweek	40 ppm	
Trichloroacetic acid in urine	End of workweek	10 mg/l	Ns, Cf
Total trichloroethanol in urine	End of shift at end of workweek	30 mg/l	Ns, Cf
Total trichloroethanol in blood	End of shift at end of workweek	1 mg/l	Ns
Methyl ethyl ketone (MEK)			
MEK in urine	End of shift	2 mg/l	
Organophosphorus cholinesterase inhibitors			
Cholinesterase activity in red cells	Discretionary	70% of individual's baseline	B, Ns, Cf
Parathion			
Total p-nitrophenol in urine	End of shift	0.5 mg/l	Ns, Cf
Cholinesterase activity in red cells	Discretionary	70% of individual's baseline	B, Ns, Cf
Pentachlorophenol (PCP)			
Total PCP in urine	Prior to the last shift of workweek	2 mg/l	B
Free PCP in plasma	End of shift	5 mg/l	B
Perchloroethylene			
Perchloroethylene in end-exhaled air	Prior to the last shift of workweek	10 ppm	
Perchloroethylene in blood	Prior to the last shift of workweek	1 mg/l	
Trichloroacetic acid in urine	End of workweek	7 mg/l	Ns, Cf
Phenol			
Total phenol in urine	End of shift	250 mg/g creatinine or 15 mg/hr	B, Ns

Table 4.35 Cont'd

<i>Airborne chemical Determinant</i>	<i>Sampling time</i>	<i>BEI</i>	<i>Notes</i>
Styrene			
Mandelic acid in urine	End of shift	1 g/l 0.8 g/g creatinine	Ns Ns
Styrene in mixed-exhaled air	Prior to next shift	40 ppb	Cf
Phenylglyoxylic acid in urine	End of shift	250 mg/l 240 mg/g creatinine	B, Ns
Styrene in mixed-exhaled air	During shift	18 ppm	Cf
Styrene in blood	End of shift	0.55 mg/l	Cf
	Prior to next shift	0.02 mg/l	Cf
Toluene			
Hippuric acid in urine	End of shift	2.5 g/g creatinine	B, Ns
	Last 4 hrs of shift	3 mg/min	
Toluene in venous blood	End of shift	1 mg/l	Cf
Toluene in end-exhaled air	During shift	20 ppm	Cf
Trichloroethylene			
Trichloroacetic acid in urine	End of workweek	100 mg/l	Ns
Trichloroacetic acid and trichloroethanol in urine	End of shift at end of workweek	300 mg/l 320 mg/g creatinine	Ns
Free trichloroethanol in blood	End of shift at end of workweek	4 mg/l	Ns
Trichloroethylene in end-exhaled air	Prior to the last shift of workweek	0.5 ppm	Cf
Xylenes			
Methylhippuric acids in urine	End of shift	1.5 g/g creatinine,	
	Last 4 hrs of shift	2 mg/min	

Sc An identifiable population may have an increased susceptibility to the effect of the chemical, leaving it unprotected by the BEI.

B The determinant is usually present in a significant amount in biological specimens collected from subjects not occupationally exposed.

Ns The determinant is non-specific, i.e. observed after exposure to other chemicals.

Cf The biological determinant is an indicator of exposure to the chemical but the quantitative interpretation of the measurement is ambiguous.

It is advisable to consult the specific documentation published in the Documentation of Threshold Limit Values and Biological Exposure Indices.

Control of substances hazardous to health

In Great Britain the COSHH Regulations cover virtually all substances hazardous to health. (Asbestos, lead, materials producing ionizing radiations and substances below ground in mines, which have their own legislation, are excluded.)

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:

- Assess the risk to health arising from work, and what precautions are needed (see Figure 4.5).
- 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 assessment requirement involves a systematic review.

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;
- 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 1A of the Approved List under the Classification, Packaging and Labelling of Dangerous Substances Regulations 1984. (Anything listed as very toxic, toxic, corrosive, harmful or irritant is covered by COSHH.)

2 What harmful effects are possible?

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.

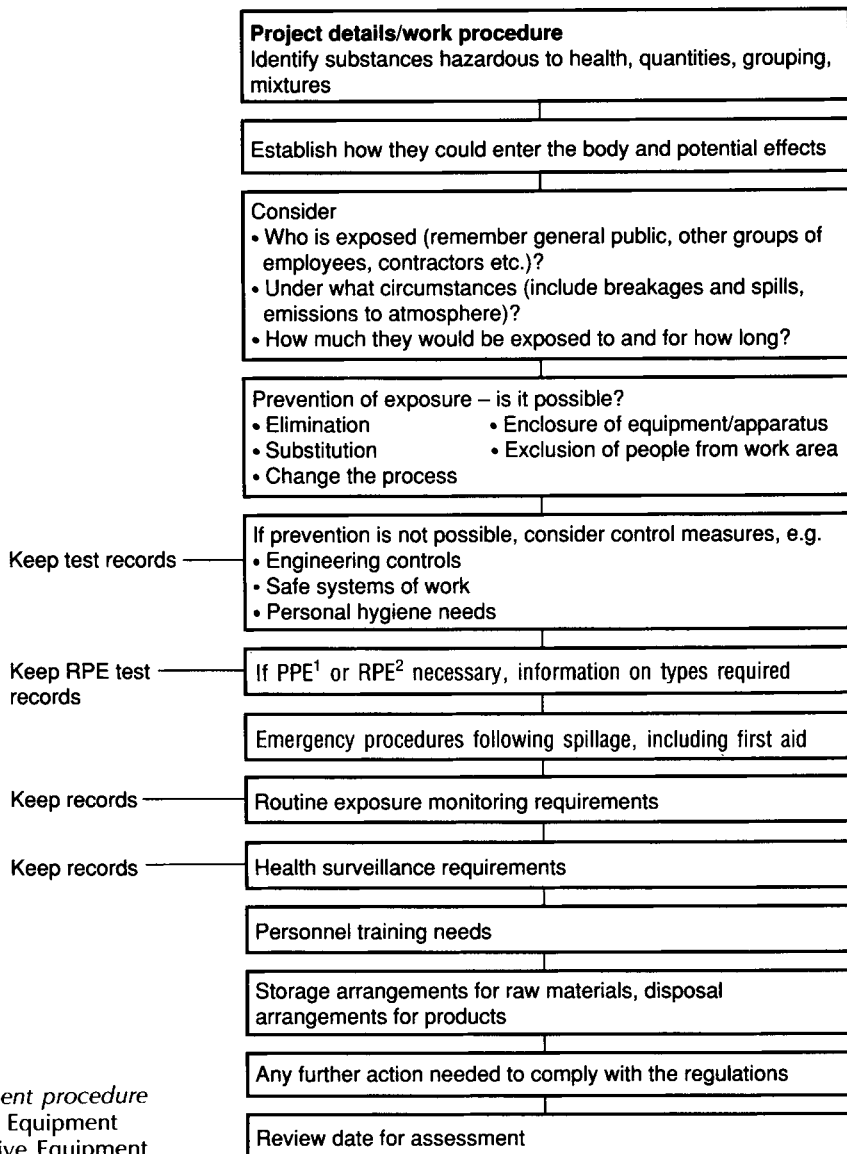


Figure 4.5 COSHH assessment procedure

¹ PPE = Personal Protective Equipment

² RPE = Respiratory Protective Equipment

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? (N.B. 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 possible length of time,
- how likely exposure is,

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.

Control

Control may mean preventing exposure (refer to page 47) by:

- removing the hazardous substance by a change in the process;
- substitution of the hazardous substance by a safer one, or using it in a safer form;

or, if the above are not reasonably practicable, by:

- total enclosure of the process;
- using partial enclosure and extraction equipment;
- general (i.e. dilution) ventilation;
- use of safe systems of work and handling procedures, and exclusion of personnel and reduction of periods of exposure.

In choosing method(s) to control exposure, COSHH limits the use of personal protective equipment (e.g. respirators, dust masks, protective clothing) as the means of protection to those situations *only* where other measures cannot adequately control exposure.

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 74.

Maintenance, examination and testing of control measures

An employer has specific obligations to ensure all control measures are kept in an 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 a record kept. Respirators and breathing apparatus must also be examined frequently.

Monitoring

The exposure of workers should be monitored in certain cases, e.g.

- 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.

A record should be kept of any monitoring.

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 4.36. Advice on health surveillance is also given for the agents listed in Table 4.37.

Information supply

There is requirement to 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.

Table 4.36 UK health surveillance requirements**Medical surveillance is required unless exposure is insignificant** (Schedule 5 to COSHH Regn 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
1-Naphthylamine and its salts	In manufacture, formation or use of these substances
Orthotolidine and its salts	
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	
Trichlorethylene	In manufacture of blocks of fuel consisting of coal, coal dust, coke or slurry with pitch as a binding substance
Pitch	

Health surveillance is appropriate unless exposure is insignificant (Control of Carcinogenic Substances ACOP, 15–18)

Any substance which under the Classification, Packaging and Labelling of Dangerous Substances Regulations 1984 (SI 1984/22, amended by SI 1986/1922 and SI 1988/766) has been assigned the 'risk phrase', 'R45: May Cause Cancer', and which is listed in Part (A) of the approved list.

Aflatoxins
 Arsenic and its inorganic compounds
 Benzo(α)pyrene
 Beryllium and beryllium compounds
 Insoluble chromium (VI) compounds
 Mustard gas (B,B'-Dichlorodiethyl sulphide)
 Inorganic nickel compounds arising during the refining of nickel
 Ortho-toluidine
 Coal soots, coal tar, pitch and coal tar fumes
 Non-solvent refined mineral oils and contaminated used mineral oils
 Auramine, in manufacture
 Leather dust in boot and shoe manufacture, arising during preparation and finishing
 Hardwood dusts
 Isopropyl alcohol manufacture (strong acid process)
 Rubber industry (processes giving rise to dust and fume)
 Magenta manufacture
 3,3'-Dimethoxy benzidine (dianisidine) and its salts
 1-Naphthylamine and its salts
 4-Nitrobiphenyl
 Orthotolidine and its salts
 Vinyl chloride monomer (VCM)

Other agents/operations and relevant regulations

Asbestos

Control of Asbestos at Work
Regulations 1987

Compressed air (other than diving operations)

The Work in Compressed Air Special
Regulations 1958

Table 4.36 Cont'd

<i>Substance</i>	<i>Process</i>
Diving operations	Diving Operations at Work Regulations 1981
Ionizing radiations	Ionizing Radiations Regulations 1985
Lead	Control of Lead at Work Regulations 1980 (HSE Guidance Note EH 29)
Mine dusts	The Coal Mines (Respirable Dust) Regulations 1975

Table 4.37 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
Biological monitoring	
Cadmium	EH 1
Mercury	{ EH 17 MS 12
Trichloroethylene	EH 5
Biological effect monitoring	
Organophosphorus pesticides	MS 17

Flammable chemicals

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) or 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 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 or result in oxygen deficiency.

Ignition and propagation of a flame front

Normally flame propagation requires

- (a) fuel, gas or vapour (or combustible dust) within certain limits of concentration,
- (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 5.1), must generally be present.

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. Some chemicals undergo spontaneous combustion (see page 142).

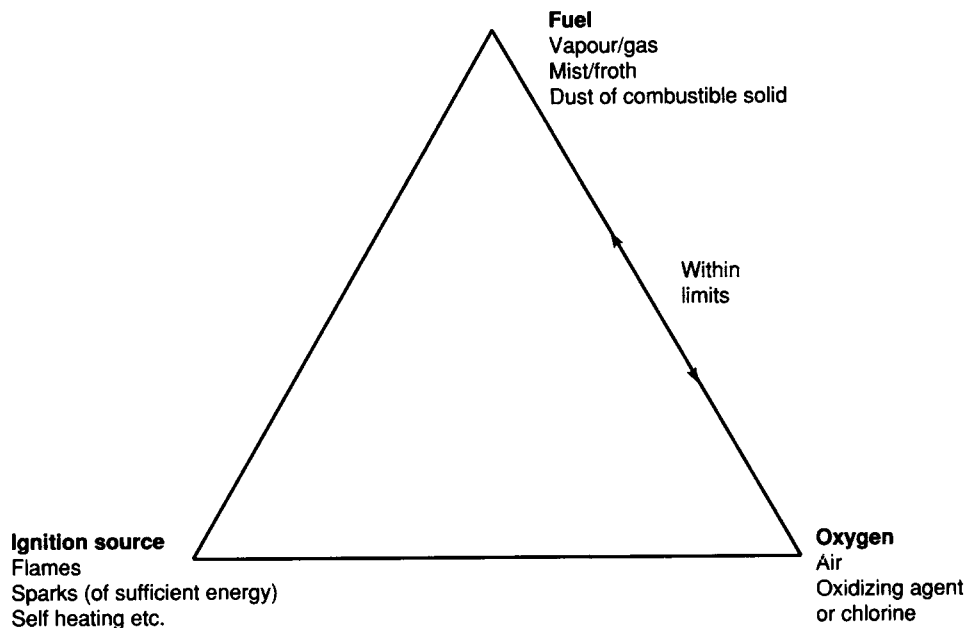


Figure 5.1 *Fire triangle*

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 5.1.

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 5.1 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. Typical flash points are quoted in Table 5.1 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 $<32^{\circ}\text{C}$ 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 contaminant.

Vapour density

The density of a vapour or gas at constant pressure is proportional to its molecular weight and inversely proportional to temperature. Since most gases and vapours have molecular weights 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 5.1 includes vapour density values.

Dust explosions

Increasing the surface area of a combustible solid enhances the ease of ignition. Solid particles less than about $10\mu\text{m}$ in diameter settle slowly in air and comprise 'float dust'. Such particles behave, in some ways, similarly to gas and, if the solid is combustible, a flammable dust–air mixture containing a distribution of particle sizes can form within certain limits.

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 5.2.

Table 5.1 Properties of flammable chemicals

<i>Substance</i>	<i>Specific gravity</i>	<i>Vapour density (air = 1)</i>	<i>Flash point⁽¹⁾ (°C)</i>	<i>Ignition temp. (°C)</i>	<i>Flammable limits⁽¹⁾ (%)</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 ²⁰	10/8
Acetaldehyde	0.78	1.52	−38	185	4–57	21	−124	∞	—
Acetanilide	1.21/4	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	—	—	63 exp.	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 ⁰	10 atm/26
Ammonium nitrate	1.7	—	—	—	exp.	210/11 mm dec.	169	118 ⁰	—
<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	—	—	—
<i>n</i> -Amyl alcohol	0.82	3.0	33	300	1–10	137	−79	sl. sol.	1/14

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
iso-Amyl alcohol	0.81	3.0	43	347	1–9	132	—	sl. sol.	—
tert-Amyl alcohol	0.81	3.0	19	437	1–9	102	–12	sl. sol.	—
Amylamine	0.8	3.0	7oc	—	—	103	–55	∞	—
<i>n</i> -Amyl bromide	1.22	5.2	32	—	—	130	–95	insol.	—
Amylene	0.66	2.4	–2	273	1.5–9	30	–124	insol.	—
<i>n</i> -Amyl ether	0.74	5.46	57	171	—	190	–70	insol.	—
iso-Amyl formate	0.89	4.0	26	—	—	131	–74	sl. sol.	—
Amyl mercaptan	0.84	3.59	18	—	—	127	–76	insol.	13/25
iso-Amyl nitrate	0.99	—	52	—	—	152–7	—	sl. sol.	—
Amyl nitrite	0.85	4.0	10	209	—	104	—	sl. sol.	—
Aniline	1.02	3.22	70	770	1.3	184	–6	sol.	1/35
<i>o</i> -Anisaldehyde	1.12	—	118	—	—	250	38	insol.	—
Anisole	1.0	3.72	52oc	—	—	154	–37	insol.	10/42
Anthracene	1.25	6.15	121	540	0.6–	340	217	insol.	1/145
Anthraquinone	1.44	7.16	185	—	—	380	286	insol.	1/190
Asphalt	1.1	—	204+	485	—	370–470	—	—	—
Aziridine	0.83	1.5	–11	322	3.6–46	56	–72	∞	—
Benzaldehyde	1.04	3.7	64	192	—	178	–26	sl. sol.	1/26
Benzene	0.88	2.8	–11	562	1.4–8	80	5.4	sl. sol.	10/26
Benzene monochloride, see Chlorobenzene									
Benzoic acid	1.32	4.2	121	574	—	249	122	sl. sol.	1/96
<i>p</i> -Benzoquinone, see Quinone									
Benzonitrile	1.2	—	85oc	—	—	191	–13	—	1/28
Benzotrifluoride	1.19	5.04	12	—	—	101	–29	insol.	11/0
Benzoyl chloride	1.22	4.88	72	—	—	197	–0.5	dec.	1/32
Benzoyl peroxide	1.33	—	—	80	—	exp.	106	sl. sol.	—
Benzyl acetate	1.06	5.1	102	461	—	214	–51.5	sl. sol.	1/45
Benzyl alcohol	1.04	3.7	101	436	—	206	–15.3	4	1/58
Benzyl amine	0.98	—	63	—	—	185	—	∞	—
Benzyl benzoate	1.11	7.3	148	481	—	323	21	insol.	—
Benzyl 'cellesolve'	1.1	5.3	129	352	—	256	–75	—	—
Benzyl chloride	1.10	4.36	67	585	1.1–	179	–39	insol.	—
Benzylidene chloride, see Benzal chloride									
Benzyl mercaptan	1.06	4.3	70	—	—	194	—	insol.	—
Bicyclohexyl	0.9	5.7	74	244	1–5	240	2	—	—
Biphenyl	1.2	5.3	113	540	0.6–5.8	256	70	insol.	—
2-Biphenylamine	1.16	5.8	—	452	—	299	49	insol.	—
Borneol	1.01	5.31	66	—	—	—	212subl	insol.	—

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
Boron hydrides, see Di-, Penta-, or Deca-Boranes									
Bromobenzene	1.50	5.4	51	566	—	155	−31	insol.	10/40
1-Bromobutane, see Butyl bromide									
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	49oc	—	—	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 ¹⁵	—
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
Butyl cellosolve	0.91	4.1	61	244	1.1–12.7	171	<−40	∞	0.6/20
n-Butyl chloride	0.88	3.2	7	471	1.9–10.1	78	−123	0.07	—
tert-Butyl chloride	0.85	3.2	<21	—	—	51	−27	sl. sol.	—

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
1,3-Butylene glycol	1.0	3.2	121	394	—	208	<−50	—	0.06/20
2,3-Butylene glycol	1.0	3.1	85	402	—	180	19	—	0.17/20
Butylene oxides	0.8	2.5	−15	—	1.5–18.3	63	—	—	—
Butyl ether, see Dibutyl ether									
<i>n</i> -Butyl formate	0.91	3.5	18	322	1.7–8	107	−90	sl. sol.	40/32
iso-Butyl formate	0.89	—	<21	—	—	98	−95	1.1 ²²	—
Butyl hydroperoxide	0.86	2.1	27	—	—	dec.	6	sol.	—
in heptane	0.68	—	−4	223	1.2–6.7	98	—	—	—
in hexane	0.69	—	−22	234	1.2–7.5	69	—	—	—
in pentane	0.70	—	−40	309	1.5–7.8	36	—	—	—
Butyl lactate	1.0	5.0	71	382	—	188	−43	—	0.4/20
Butyl mercaptan	0.84	3.1	2	—	—	98	−116	sl. sol.	—
Butyl methacrylate	0.89	4.8	52	294	2–8	163	—	insol.	5/20
Isobutyl methyl ketone		3.5	17	460	1.2–8	126	−57	—	—
tert-Butyl peracetate	0.93	—	27	—	—				
tert-Butyl perbenzoate	1.0	—	88	—	—	113dec	—	—	0.3/50
Butyl peroxyphthalate (in 75% sol. of mineral spirits)		—	>68	—	—		−19		
Butyl peroxyisobutyl acetate, see Butyl peroxyphthalate									
Butyl vinyl ether	0.77	3.4	−9	—	—	94	−92	insol.	—
<i>n</i> -Butyraldehyde	0.82	2.5	−6.7	230	2.5–	76	−99	4	—
iso-Butyraldehyde	0.79	2.5	−40	254	1.6–10.6	64	−66	4	—
<i>n</i> -Butyric acid	0.96	3.0	66	452	2–10	164	−7.9	∞	0.4/20
iso-Butyric acid	0.95	3.0	62	502	—	154	−47	20 ²⁰	—
<i>n</i> -Butyric anhydride	0.97	5.4	88	307	—	198	−73	dec.	—
2-Butyrolactone	1.05	3.0	98	—	—	206	−44	∞	—
<i>n</i> -Butyronitrile	0.8	—	26	—	—	117	−112	sl. sol.	—
Butyryl chloride	1.03	3.7	<21	—	—	107	−89	dec.	—
Camphor	0.99	5.24	66	466	0.6–3.5	204	180	sl. sol.	—
Caproic acid	0.93	4.0	102	—	—	205	−5.4	1.1 ²⁰	0.2/20
Capryl alcohol, see 2-Octanol									
Caprylaldehyde	0.8	4.5	52	—	—	168	—	—	—
Caprylic acid, see Octanoic acid									
Caprylic alcohol, see 1-Octanol									
Carbitol, see Diethylene glycol monoethyl ether									
Carbolic acid, see Phenol									
Carbon disulphide	1.26	2.6	−30	100	1–44	46	−112	0.2 ⁰	400/28
Carbon monoxide	0.81	0.97	—	609	12.5–74	−192	−207	0.004 ⁰	—

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
Carbon oxysulphide, see Carbonyl sulphide									
Carbonyl sulphide	1.07	2.1	—	—	12–29	–50	–138	80 ¹⁴	
Carvene, see 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 (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, see Epichlorohydrin									
Chloroethane, see Ethyl chloride									
Chloroethanol, see Ethylene chlorohydrin									
Chloromethane, see 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 (mixe phenols)	1.07	—	74–82	336	—	200–250	—	—	—
Cresylic acid, see <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 ²⁰	—
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

Table 5.1 Cont'd[illegible]

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Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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 ₂	40	–97	2 ²⁰	—
Dichloromonofluoromethane	1.48	3.8	—	552	—	9	–135	insol.	—
1,1-Dichloro-1-nitroethane	1.42	4.97	76	—	—	124	—	0.5 ²⁰	—
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 ²⁸	—
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 ³⁰	—
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 ¹²	1/50
Diethylcarbonate	0.98	4.07	25	—	—	126	–43	insol.	10/24
Diethyl cellasolve	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	–1.23								
Diethyl ether, see Ethyl ether	0.95	3.5	102	399	—	207	–39	∞	—
Diethyl ethyl phosphonate	1.03	5.7	105	—	—	83	—	sl. sol.	—
Diethyl ketone	0.82	2.96	13	452	—	101	–42	4.7 ²⁰	—
Diethyl malonate	1.06	5.5	93	—	—	199	–50	2.1 ²⁰	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	—	208 dec.	–25	insol.	1/47
Diglycol, see 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 (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	—	—	—
N,N-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.	—

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Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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, see Cellosolve									
2-Ethoxy ethylacetate, see 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 ²⁰	100/27
Ethyl acetoacetate	1.03	4.48	84	—	—	181	–45	13 ¹⁷	1/29
Ethyl acrylate	0.92	3.5	16	273	1.8–	100	<–72	sol.	29/20
Ethyl alcohol, see Ethanol									
Ethyl aldehyde, see 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 ¹⁵	10/26
Ethyl benzoate	1.15	5.17	>96	—	—	213	–35	insol.	1/40
Ethyl bromide, see 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 ²⁵	10/15
Ethyl chloride	0.92	2.2	–50	519	3.6–15.4	12	–139	0.45 ⁰	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 ²⁵	1/68
Ethyl cyanide, see Propionitrile									
Ethylene	0.001	1.0	—	450	3.1–32	–104	–169	26 ⁰	—
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, see Butyl cellosolve									
Ethylene glycol monoethyl ether, see Cellosolve									
Ethylene glycol monomethyl 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 ²⁰	442/20
Ethyl ethynyl ether, see Ethoxyacetylene									
Ethyl formate	0.95	2.55	–20	455	2.7–13.5	54	–79	11 ¹⁸	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	—	∞	—

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Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
<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 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 ⁰	—
Hydrogen sulphide	1.5	1.2	—	260	4.3–46	−60	−83	437 ⁰	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	38–66	229	0.7–5	170–300	<−46	—	—
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
α-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	∞	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

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
Methyl cellosolve	0.97	2.62	46oc	288	2.5–14	125	–87	∞	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
α-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 ethyl ketone	—	—	52–93	—	—	—	110exp.	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
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
α-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	—	—

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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, see <i>n</i> -Amyl alcohol									
2-Pentanol	0.81	3.03	39	347	1.2–9.0	119	—	v. sol.	—
2-Pentanone, see Methyl <i>n</i> -propyl ketone									
3-Pentanone, see Diethyl ketone									
Pentene, see Amylene									
<i>n</i> -Pentyl acetate, see <i>n</i> -Amyl acetate									
sec-Pentyl acetate, see sec-Amyl acetate									
Pentyl alcohol, see <i>n</i> -Amyl alcohol									
Pentyl amine, see <i>n</i> -Amylamine									
iso-Pentyl nitrite, see 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	—	—
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 ²⁰	<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	—	—	—
						at 1 mm			
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	—
							at 43 atm		
Phosphorus pentasulphide	2.03	—	—	142	—	514	276	insol.	—
Phosphorus tribromide	2.8	—	—	100	—	173	−40	insol.	10/48

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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, see 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, see 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, see 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, see 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

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
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– at 200°C	281	110	sol.	1/108
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 ⁰	—
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
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 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

Table 5.1 Cont'd

Substance	Specific gravity	Vapour density (air = 1)	Flash point ⁽¹⁾ (°C)	Ignition temp. (°C)	Flammable limits ⁽¹⁾ (%)	Boiling point (°C)	Melting point (°C)	Solubility in water (g/100 g)	Vapour pressure (mm Hg/°C)
<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 ₂ 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 11 mm			
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 dimethylhydrazine	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	-150c	458	5.6-11.4	32	-122	insol.	—

Table 5.1 Cont'd

<i>Substance</i>	<i>Specific gravity</i>	<i>Vapour density (air = 1)</i>	<i>Flash point⁽¹⁾ (°C)</i>	<i>Ignition temp. (°C)</i>	<i>Flammable limits⁽¹⁾ (%)</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>
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.

⁽¹⁾ Unless otherwise stated, flammable limits relate to ambient temperature and atmospheric pressure and flash points relate to closed cup measurements.

Table 5.2 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)⁽¹⁾</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	—	Guncotton ignition source in pressure test
Aluminium—nickel alloy	950	540	0.190	80	96	10 000	—	
Aluminium—silicon alloy	670	—	0.040	60	85	7500	—	
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	—	
α, α'-Azo isobutyronitrile	430	350	0.015	25	134	8000	—	
Barley	370	—	—	—	—	—	—	
Benzethonium chloride	380	410	0.020	60	91	6700	—	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mj)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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>P</i> - <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	20000	—	
Calcium stearate	400		0.025	15	97	>10000	—	
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							

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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
<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

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
Colophony	325	Melts		—			—	See also Gum manila
Copal	330	Melts		—	68	—		
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	—	—	—	—	—	—	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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	—	—	—	—	—	—	
Dinitrotoluamide	500	—	0.050	15	153	>10 000	—	
Diphenyl	630	—	0.015	20	82	3700	—	
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					
Ferrovanadium	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		

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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	—	
p-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	—	—	—	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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 trichloroethyl phosphate	540	—	—	—	—	—	—	Group (b) dust
Moss, Irish	530	230	Did not ignite		21	300	—	
Naphthalene	575	Melts	—	—	87	—	—	
β-Naphthalene-azo-dimethyl aniline	510	Melts	0.020	50	70	2300	—	
β-Naphthol	670	—	—	—	—	—	—	
Naphthol yellow	415	395	—					
Nigrosine hydrochloride	630	—	—			—	—	
<i>p</i> -Nitro- <i>o</i> -anisidene	400				—			
<i>p</i> -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	—	
<i>p</i> -Nitro- <i>o</i> -toluidine	470	—	—	—	—	—	—	
<i>m</i> -Nitro- <i>p</i> -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	—	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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		
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 amatol	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		—	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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	—	—	—			—	
Sodium xylene sulphonate	490	—	—	—		—	—	
Soot	>690	535	—	—	Did not ignite		—	
Sorbic acid	440	460	0.020	15	106	>10 000	5	Inert gas nitrogen
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				—		—	
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	

Table 5.2 Cont'd

Dust	Minimum ignition temperature (°C)		Minimum explosible concentration (g/l)	Minimum ignition energy (mJ)	Maximum explosion pressure (psi) ⁽¹⁾	Maximum rate of pressure rise (psi/s)	Maximum oxygen concentration to prevent ignition (% by volume)	Notes
	cloud	layer						
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	—	—	—	—	—	
Trinitro toluene	—	—	0.070	75	63	2100	—	
s-Trioxane	480	—	0.143	—	85	600	—	
α,α'-Trithiobis (N, N-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	not	ignite	—	—	Group (b) dust
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	

⁽¹⁾ 1 psi = 0.069 bar.

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 157).

There is a critical oxygen content below which ignition of combustible dusts will not occur and this can provide a means for safe operation under an inert atmosphere.

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 5.3, and temperatures in Table 5.4. They include:

- Naked flames (e.g. Bunsen burners, welding torches, blow lamps, furnaces, pilot lights, matches).
- 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 $\leq 3000^{\circ}\text{C}$. A thermite flash can result from the 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.

Petroleum vapour is unlikely to be ignited by impact of steel on steel produced by hand. Power operation can however produce incandescive 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 incandescive irrespective of striking material. Friction in bearings is a common ignition source.

- Hot surfaces (e.g. lamp filaments, hot pipes, radiators, ovens, portable heaters, cigarettes, burning embers).
- Engines. 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.
- Sparks due to static electricity associated with the separation of two dissimilar materials (Table 5.5). 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

Table 5.3 Sources of ignition**Mechanical sources**

Friction

Metal to metal
 Metal to stone
 Rotary impact
 Abrasive wheel
 Buffing disc
 Tools, drill
 Bolt studs
 Bearings
 Misaligned machine parts
 Broken machine parts
 Choking or jamming of material
 Poor adjustment of power drives
 Poor adjustment of conveyors

Missiles

Hot missiles
 Missile friction

Metal fracture

Cracking of metal

Electrical sources

Electrical current

Switch gear
 Cable break
 Vehicle starter
 Broken light
 Electric motor

Electrostatic

Liquid velocity
 Surface charge
 Personal charge
 Rubbing of plastic or rubber
 Liquid spray
 Mist
 Water jetting
 Powder flow on plastic
 Water settling

Lightning

Direct strike
 Hot spot
 Induced voltage

Stray currents

Railway lines
 Cable break
 Arc welding

Radio frequency

Aerial connection
 Intermittent contact

Thermal sources

Hot surface

Hot spot
 Catalyst hot spots
 Sparks from incinerators, flarestacks, chimneys
 Vehicle exhaust
 Steam pipes
 Refractory lining, hot slag
 Foreign metal in crushing and grinding equipment
 Electric heater
 Smoking
 Glowing embers, brands
 Drying equipment
 Molten metal or glass
 Heat transfer salt
 Hot oil/salt transfer lines

Table 5.3 Cont'd

	Boiler ducts or flues Electric lamps Hot process equipment Welding metal
Self-heating	Oxidation Reaction Activated carbon
Flames	Pilot light Matches, cigarette lighters Cutting, welding Portable gas heaters Stoves Burners Arson
Compression	Pressure change Piston
Engines	Exhaust Engine overrun Hydraulic spray into air intake
Diffusion	High pressure change
Chemical sources	
Peroxides	Oxygen release Unstable Decomposition
Polymerization	Exothermic reaction Catalyst Lack of inhibitor Crystallization
Spontaneous	Pyrophoric deposit Deposits Water reactive Sulphides Oily rags, oil impregnation of lagging Heat transfer salt
<i>Reactions with other substances</i>	
Thermite reaction	Rust Aluminium, aluminium alloys
Unstable substances	Acetylides
Decomposition	Initiator Temperature Catalyst

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.

- **Lightning.** Protection is generally provided by earthing with low resistance, e.g. 7 Ω , which should be short and direct. The recommended value for protection of plant is $\leq 10 \Omega$.

Table 5.4 Approximate temperatures of common ignition sources

Flame/spark sources	<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
Non-flame sources	
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

Table 5.5 Operations which may result in static charge generation

Solid–solid	Persons walking Grit blasting Conveying of powders Belts and pulleys Fluidized beds
Solid–liquid	Flow of liquids in pipelines/filters Settling of particles in liquid (e.g. rust and sludge)
Gas–liquid	Released gas (air) bubbles rising in a large tank Mist formation from LPG evaporation Splash filling Cleaning with wet steam Mist formation from high pressure water jets
Liquid–liquid	Settling of water drops in oil
Solid–gas	Mixing of immiscible liquids Pneumatic conveying of solids Fluidized beds

A material that is above its autoignition temperature will ignite spontaneously on contact with air in the correct proportions (see Table 5.1 for minimum temperature of ignition source).

Ignition of a flammable dust–air mixture is more difficult than with air–vapour

Table 5.6 Approximate temperatures at which selected substances will explode, without the application of a flame

Solids	<i>Temperature⁽¹⁾(°C)</i>	
	137	139 ⁽²⁾
Gun cotton (loose)	169	230
Cellulose dynamite	174	
Blasting gelatine (with camphor)	175	
Mercury fulminate	186	201
Gun cotton (compressed)	197	200
Dynamite	203	209
Blasting gelatine	257	
Nitroglycerin	270	300
Gunpowder		
Gases		
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

⁽¹⁾ 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.

⁽²⁾ 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.

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 5.6.

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 5.7. 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 5.9). 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.

Table 5.7 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	
Animal feedstuffs	
Beans	
Bone meal, bone black	
Brewing grains, spent	Leather scrap
Carbon	Maize
Celluloid	Manure
Colophony powder material	Milk products
Copper powder	Monomers for polymerization
Copra	Oleic acid impregnated fibrous coal
Cork	Palm kernels
Cotton waste	Paper waste
Cotton	Peat
Cottonseed	Plastic, powdered
Distillers dried grain	Rags, impregnated
Fats	Rapeseed
Fertilizers	Rice bran
Fishmeal	Rubber scrap
Flax	Sawdust
Foam and plastic	Seeds
Grains	Seedcake
Grass	Silage
Gum rosin	Sisal
Hay	Soap powder
Hemp	Soya beans
Hides	Straw
Iron filings/wool/borings	Sulphur
Iron pyrites	Varnished fabric
Ixtle	Wood chips
Jaggery soap	Wood fibreboard
Jute	Wood flour
Lagging contaminated with oils etc.	Wool waste
Lamp-black	Zinc powder

Table 5.7 Cont'd

Fibrous materials are subject to self-heating when impregnated with the following vegetable/animal oils

(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

Other materials subject to self-heating (depending upon composition, method of drying, temperature, moisture content)

Desiccated leather
 Leather scraps
 Dried blood
 Household refuse
 Leather meal

Table 5.8 Characteristics of some organometallic compounds in common use

Alkyl magnesium halides (Grignard reagents)	Usually prepared and handled in organic solvent For alkyl groups of ≤ 4 carbon atoms, the compounds react vigorously with water and the resulting alkane ignites
Butyllithium	Pale yellow, caustic, extremely flammable liquid May ignite if exposed to air Reacts violently with water
Diethyl aluminium chloride	Colourless corrosive liquid Ignites immediately upon contact with air 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 Ignites in air
Nickel carbonyl	Yellowish, volatile, toxic liquid, oxidizes in air and explodes at $\sim 60^\circ\text{C}$ 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 5.10 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	uncombined	Very little reaction unless at white heat
Nickel	Ni	1.75		
Tin	Sn	1.72		
Lead	Pb	1.55		
Hydrogen	H	2.20	Sometimes found uncombined	Inactive with water or steam
Phosphorus	P	2.06		
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		

acetylene), alkali metals (hydrogen), organometallics (hydrocarbons – see Table 5.8), and where the heat of reaction is sufficient to ignite the gas. Thus metals which are less electronegative than hydrogen (see Table 5.10) 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. Ignition results in a fireball and missiles.

- Dust explosion (refer to page 108).
- Explosion due to thermal deflagration or detonation of a solid or liquid.

Other types of explosion involve,

- Pressure rupture, due to rapid release of high pressure.
- Steam explosion: rapid vaporization of water within molten metal, molten salts or hot oil (refer to page 18).

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 for fire/explosion.
- 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.

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 5.11.

Refer also to ‘Fire extinguishment’ (page 149).

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.

Table 5.11 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
Eliminate ignition sources
Consider need for inerting, flame arresters, pressure relief valves, explosion vents (venting to safe location)
Apply appropriate zoning criteria, e.g. with respect to standards of electrical equipment (refer to Table 11.5)
Set up procedures to prevent inadvertent introduction of other ignition sources and to avoid oxygen enrichment: <ul style="list-style-type: none">Physical segregation, e.g. fencesWarning signs to indicate flammable hazard, no smoking etc.Permits-to-work (including hot work permits)Safe systems of work to control plant modifications etc.
Eliminate static
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
Consider need for checks on oxygen levels or loss of inert medium
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>

- Containment of explosion overpressure or safe venting of forces, e.g. via blow-off panels, doors.
- Limitation of inventory.
- Restriction of spread by means of baffles, chokes or by advance inerting.
- Use of water sprays.
- Good housekeeping, particularly to avoid a devastating secondary explosion.

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.

- 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. Fire detection may be 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.

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.

Fire-extinguishing materials

The penetration and cooling action of *water* is required with Class A fires, e.g. those involving paper, wood, textiles, refuse. 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 5.1 under 'Specific gravity'), so that water as a

Table 5.12 Portable fire extinguishers

<i>Extinguisher type</i>	<i>Water</i>	<i>Carbon dioxide</i>	<i>Dry powder</i>	<i>Foam</i>	<i>Vaporizing liquid</i>	<i>Fire blanket</i>	<i>Sand</i>
Recommended colour – to BS 5423	Signal red	Black	French blue	Pale cream	Emerald green	(Red)	(Red bucket)
Class A fire Wood, cloth, paper or similar combustible material <i>Cooling by water most effective</i>	Most suitable	Small fires only	Small fires only	Yes	Small fires only ⁽¹⁾	No, except for personal clothing on fire	No
Class B fire Flammable liquids, petrol, oils, greases, fats <i>Blanketing/smothering most effective</i>	Dangerous	Most suitable	Most suitable	Most suitable ⁽²⁾	Small fires only ⁽¹⁾	Most suitable Small fires only	Small fires only
Electrical plant, electrical installations <i>Non-conductivity of extinguishing agent most important</i>	Dangerous	Most suitable	Most suitable	No	Yes ⁽¹⁾	No	No

⁽¹⁾ Toxic products may be produced: care must be exercised after use in confined spaces.

⁽²⁾ Special foam required for water-miscible liquids.

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.

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.

Portable extinguishers and *fire blankets* are normally provided at strategic points in the work area. See Table 5.12.

Table 5.13 General fire precautions

Area designation	Zoning for electrics Control portable heaters etc. No smoking Restricted areas
Electrical equipment	Regular inspection and maintenance by qualified electricians Prohibition of makeshift installations
Waste disposal	Prevention of combustible waste accumulation in corners, passageways or other convenient ‘storage’ areas
Storage	Segregated storage Uncongested storage of combustibles: gangways/adequate breaks Material stacked in the open should be away from windows Flammable liquids in properly designed storerooms: bulk quantities in fixed, banded, adequately spaced tanks
Contractors	Clearance Certificate control of contractors/temporary workers Close control of temporary heating, lighting, cooking etc.
Escape/access	Escape doors and routes must be kept free of obstructions Access for emergency services must be maintained

Table 5.13 Cont'd

Fire equipment	Fire alarm and fire-fighting equipment must be regularly inspected, maintained and tested Portable extinguishers to have designated locations/be of correct type. Instructions must be provided as to where and how to use them. Practise is necessary
Flues	Passages for services or other ducts must be adequately fire-stopped to prevent their acting as flues for fire/smoke transmission
Sprinklers	Maintain sprinkler systems Institute alterations if building is modified, use changes etc. Observe use specifications, e.g. for stack heights, fire loading
Prevention of arson	Control access at all times Screen employees and casual labour Lock away flammable substances and keep combustibles away from doors, windows, fences Provide regular fire safety patrols, even where automatic systems are provided Secure particularly storage and unmanned areas
Fire and smoke stop doors	Ensure that fireproof doors and shutters are self-closing Keep <i>all</i> doors free from obstruction Ensure that fire check doors are kept closed

Table 5.14 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

Fire precautions

A whole range of precautions may be based on the principles summarized earlier. However, general precautions, applicable to the majority of work situations, are listed in Table 5.13, many of which are included in legal requirements. For example, in the UK The Fire Precautions Act 1971 specifies requirements for fire resistance of surfaces and building structure, assessment of risk, means of escape, means for giving warning, fire-fighting equipment, and fire instruction and drills.

The minimum fire instruction and training needs are summarized in Table 5.14.

Reactive chemicals

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 or to react violently on contact with other common chemicals, as illustrated in Figure 6.1. The case of pyrophoric chemicals is summarized in Chapter 5; other cases are summarized here.

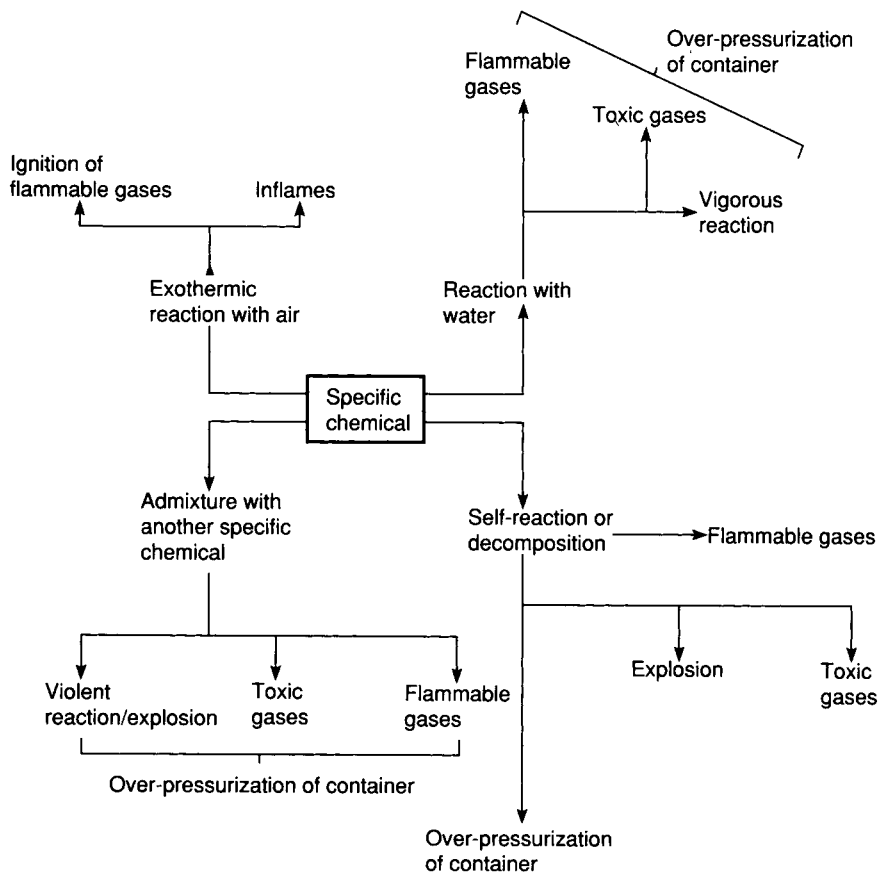


Figure 6.1 Possible reactive chemical hazards (consequences are not mutually exclusive)

Table 6.1 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

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 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 6.1. Such reactions can cause overpressure in equipment. Selected water-sensitive chlorine compounds are given in Table 6.2. 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 6.3.

Table 6.2 Examples of reactive chlorine compounds

<i>Compound</i>	<i>Description</i>	<i>Reactivity</i>
Acetyl chloride CH_3COCl	Colourless, fuming, corrosive liquid Flash point 4°C When heated, emits phosgene	Decomposes violently with water to produce heat and toxic fumes: HCl
Aluminium chloride (anhydrous) 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 Violent reaction when a stream of water hits a large amount Do not use water in vicinity
Benzoyl chloride $\text{C}_6\text{H}_5\text{COCl}$	Colourless, fuming, corrosive liquid with a strong odour Combustible: flash point 72°C Generates phosgene gas when heated	Reacts strongly with water or water vapour, producing heat and toxic/corrosive fumes Use of water must be considered carefully
Calcium hypochlorite $\text{Ca}(\text{ClO})_2$	Water soluble white crystals or powder with strong chlorine odour Non-flammable but can evolve Cl_2 and O_2 May undergo decomposition	Water spray may be used but evolves Cl_2 gas freely at ordinary temperatures with moisture
Sulphur monochloride S_2Cl_2	Yellowish-red oily fuming liquid with a strong odour Combustible: flash point 118°C Ignition temp. 233°C Liquid and vapours are irritating	Decomposes when contacted by water, to produce heat and toxic/corrosive fumes Do not allow water to enter containers: reaction can be violent Wash down spills with flooding amounts of water
Titanium tetrachloride TiCl_4	Colourless to light yellow fuming corrosive liquid Vapour is irritating	Reacts vigorously with water, liberating heat and corrosive HCl gas Reacts more strongly with hot water Use water spray to keep exposed containers cool in fire

Table 6.3 Variation in reactivity of hydrides with humid air or water

Substance	Reaction (ambient temperature)	
	Humid air	Water
Aluminium borohydride ($\text{Al}(\text{BH}_4)_3$)	Explosive	Explosive
Aluminium hydride (AlH_3)	Slow	Moderate
Antimony hydride (SbH_3)	Rapid	Very slow
Arsenic hydride (Arsine) (AsH_3)	Moderate	Very slow
Barium hydride (BaH_2)	Rapid	Rapid
Beryllium borohydride ($\text{Be}(\text{BH}_4)_2$)	Explosive	Explosive
Beryllium hydride (BeH_2)	Slow	Slow
Calcium hydride (CaH_2)	Moderately fast	Rapid
Cerium hydride (CeH_3)	Pyrophoric	Slow
Caesium hydride (CsH)	Inflames	Violent
Copper hydride (CuH)	Rapid	Slow
Diborane (B_2H_6)	Explosive	Moderate
Lead hydride (PbH_4)	Instant (unstable gas)	—
Lithium aluminium hydride (LiAlH_4)	Rapid	Violent
Lithium borohydride (LiBH_4)	Rapid	Vigorous
Lithium hydride (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 (MgH_2)	Known to ignite	Rapid
Pentaborane (B_5H_9)	Ignites	Rapid
Phosphorus hydride (PH_3)	Pyrophoric	Very slow
Potassium borohydride (KBH_4)	Very slow	Very slow
Potassium hydride (KH)	Inflames	Vigorous
Rubidium hydride (RbH)	Inflames	Violent
Silicon hydride (Silane) (SiH_4)	Explosive	Rapid
Sodium aluminium hydride (NaAlH_4)	Rapid	Ignites, may explode
Sodium borohydride (NaBH_4)	Slow	Slow
Sodium hydride (NaH)	Ignites	Violent
Uranium hydride (UH_3)	Pyrophoric	Moderate

Table 6.4 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.

Column 1	Column 2	Column 3
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

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 (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 6.4. Chemicals which are incompatible in this way must be brought into contact only under strictly controlled conditions.

Precautions

- Correct labels.
- Segregated storage, to avoid accidental mixing.
- Disposal 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 6.5.

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 (e.g. concentration, agitation, temperature, pressure) likely to arise.

For reactions with air or water, refer to pyrophoric chemicals (Chapter 5).

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 6.1); the acid should always be added cautiously to water and not vice versa. Eye 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. Moreover 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 6.6.

Table 6.5 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.

Column 1	Column 2
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, e.g. sodium, potassium, lithium, magnesium, calcium, 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, peroxide
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

Table 6.6 Common oxidizing agents classified according to stability**Relatively stable**

- Increase the burning rate of combustible materials
- Form highly flammable or explosive mixtures with finely divided combustible materials

Aluminium nitrate
 Ammonium persulphate
 Barium nitrate/peroxide
 Calcium nitrate/peroxide
 Cupric nitrate
 Hydrogen peroxide solutions (8–27.5% by weight)
 Lead nitrate
 Lithium peroxide/hypochlorite
 Magnesium nitrate/perchlorate
 Nickel nitrate
 Nitric acid (concentrations $\leq 70\%$)
 Potassium dichromate/nitrate/persulphate
 Silver nitrate
 Sodium dichromate/nitrate/nitrite/perborate/
 persulphate/chlorite ($\leq 40\%$ by weight)
 Strontium nitrate/peroxide
 Zinc peroxide

Moderately unstable/reactive

- Undergo vigorous decomposition on heating
- Explode when heated in a sealed container
- Cause spontaneous heating of combustible materials

Ammonium dichromate
 Barium chlorate
 Calcium chlorate/hypochlorite
 Chromium trioxide (chromic acid)
 Hydrogen peroxide solutions (27.5–91% by weight)
 Nitric acid (concentrations $> 70\%$)
 Potassiumbromide/chlorate/permanganate/peroxide
 Sodium chlorate/permanganate/peroxide/chlorite
 ($> 40\%$ by weight)
 Strontium chlorate

Unstable

- Explode when catalysed or exposed to heat, shock or friction
- Liberate oxygen at room temperatures

Ammonium chlorate/perchlorate/permanganate
 Benzoyl peroxide
 Guanidine nitrate
 Mercury chlorate
 Methyl ethyl ketone peroxide
 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 6.5).

Table 6.7 Atomic groupings characterizing explosive compounds

Bond groupings	Class
$-C \equiv C-$ $-C \equiv C - \text{Metal}$ $-C \equiv C - X$ $N=N$ $\begin{array}{c} \\ C \\ \diagup \quad \diagdown \end{array}$	Acetylenic Compounds Metal Acetylides Haloacetylene derivatives Diazirines
$>CN_2$	Diazo Compounds
$>C-N=O$	Nitroso Compounds
$>C-NO_2$	Nitroalkanes, C-Nitro and Polynitroaryl compounds
$\begin{array}{c} NO_2 \\ \diagup \\ C \\ \diagdown \\ NO_2 \end{array}$	Polynitroalkyl compounds
$>C-O-N=O$	Acyl or alkyl nitrites
$>C-O-NO_2$	Acyl or alkyl nitrates
$\begin{array}{c} >C-C< \\ \\ O \end{array}$	1, 2-Epoxides
$>C=N-O-\text{Metal}$	Metal Fulminates or aci-nitro salts
$\begin{array}{c} NO_2 \\ \\ -C-F \\ \\ NO_2 \end{array}$	Fluorodinitromethyl compounds
$>N-\text{Metal}$	N-Metal Derivatives
$>N-N=O$	N-Nitroso Compounds
$>N-NO_2$	N-Nitro Compounds
$>C-N=N-C<$	Azo Compounds
$>C-N=N-O-C<$	Arenediazoates
$>C-N=N-S-C<$	Arenediazo aryl sulphides
$>C-N=N-O-N=N-C<$	Bis-arenediazo oxides
$>C-N=N-S-N=N-C<$	Bis-arenediazo sulphides
$>C-N=N-N-C<$ \diagdown R	Trizaenes (R=H, -CN, -OH, -NO)
$-N=N-N=N-$	High-nitrogen compounds tetrazoles
$>C-O-O-H$	Alkylhydroperoxides, peroxyacids
$>C.CO.OOH$	
$>C-O-O-C<$	Peroxides (cyclic, diacyl, dialkyl), peroxyesters
$>C.CO.OOR$	
$-O-O-\text{Metal}$	Metal peroxides, peroxyacid salts
$-O-O-\text{Non-metal}$	Peroxoacids
$N \rightarrow Cr-O_2$	Aminechromium peroxo-complexes
$-N_3$	Azides (acyl, halogen, non-metal, organic)
$>\overline{C-N_2^+O^-}$	Arenediazoniumolates
$>C-N_2^+S^-$	Diazonium sulphides and derivatives, 'xanthates'
N^+-HZ^-	Hydrazinium salts, oxosalts of nitrogenous bases

$-N^+ - OH Z^-$	Hydroxylammonium salts
$\geq C - N_2^+ Z^-$	Diazonium carboxylates or salts
$(N-Metal)^+ Z^-$	Aminemetal oxosalts
Ar-Metal-X X-Ar-Metal	Halo-Arylmetals
N-X	Halogen Azides, N-Halogen compounds, N-Haloimides
$-NF_2$	Diffuoroamino compounds
$-O-X$	Alkyl perchlorates, Chlorite salts, Halogen oxides, Hypohalites, Perchloric acid, Perchloryl Compounds

Explosive chemicals

Explosions involving flammable gases, vapours and dusts are discussed in Chapter 5. 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 6.7 are known from experience to be 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 6.8 for peroxides. Table 6.9 lists a selection of potentially explosive compounds.

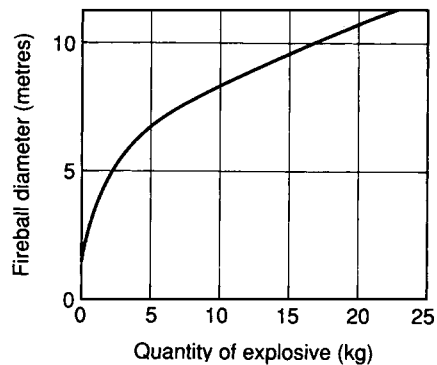
More specific definitions of 'explosives' appear in legislation, e.g. in the UK under the Explosives Act 1875 as amended, which covers:

- 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 6.10 (showing the explosive effects of small quantities of high explosives in a 6 m × 6 m single storey building) and to Figure 6.2 (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 6.11. This is used to restrict quantities in use/storage and for selection of the appropriate safety precautions. Propellant hazards are akin to those for pyrotechnics except that confinement can lead to detonation.

Figure 6.2 Diameter of fireball versus quantity of explosive**Table 6.8** Classification of organic peroxides

Peroxide class	General structures or characteristic group
Hydroperoxides	ROOH $\text{R}_m\text{Q}(\text{OOH})_n$ (Q = metal or metalloid)
α -Oxy- and α -peroxy-hydroperoxides and peroxides	contain the grouping: $\begin{array}{c} \text{OO}^- \\ \\ \text{C} \\ \\ \text{O}^- \end{array}$
Peroxides	ROOR' $\text{R}_m\text{Q}(\text{OOR})_n$ R_mQOOQR_n
Peroxyacids	$\text{R}(\text{CO}_3\text{H})_n$ RSO_2OOH
Diacyl peroxides	$\begin{array}{c} \text{O} \quad \text{O} \\ \quad \\ \text{RCOOCR}' \\ \text{O} \quad \text{O} \\ \quad \\ \text{ROCOOCR} \\ \text{O} \quad \text{O} \\ \quad \\ \text{RSOOCR} \\ \text{O} \quad \text{O} \\ \quad \\ \text{RCOOCR}' \end{array}$
Peroxyesters	$\text{R}(\text{CO}_3\text{R}')_n$ $\text{R}'(\text{O}_3\text{CR})_2$ $\begin{array}{c} \text{O} \\ \\ \text{ROCOOR}' \\ \text{O} \\ \\ \text{ROOCOOR} \\ \text{O} \\ \\ >\text{NCOOR} \\ \text{O} \\ \\ \text{RSOOR}' \\ \text{O} \end{array}$

Table 6.9 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 peractate
 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 triozonide
 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
 Phenylhydrazon 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 peroxy nickelate
 Potassium hyperoxytungstate
 Potassium peroxy pyrovanadate
 Calcium diperoxy sulphate
 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

(b) Halo-acetylenes and acetylides

Lithium bromoacetylide
 Dibromoacetylene
 Lithium chloroacetylide

Table 6.9 Cont'd

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-ylsilver
 1,3-Pentadiyn-1-ylcopper
 Dimethyl-1-propynylthallium
 Triethynylaluminium
 Triethynylantimony
 Bis(Dimethylthallium) acetylide
 Tetraethynylgermanium
 Tetraethynyltin
 Sodium phenylacetylide
 3-Buten-1-ynyldiethylaluminium
 Dimethyl-phenylethynylthallium
 3-Buten-1-ynyltriethyllead
 3-Methyl-3-buten-1-ynyltriethyllead
 3-Buten-1-ynyldiisobutylaluminium
 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 borazide
 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
 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
 Diazoacetone
 2-Diazocyclohexanone
 Diazocyclopentadiene
 1-Diazindine
 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
 Copper fulminate
 Dimethylthallium fulminate
 Diphenylthallium fulminate
 Mercury(II) methylnitrolate
 Mercury(II) formhydroxamate
 Mercury(II) fulminate
 Silver fulminate
 Sodium fulminate
 Thallium fulminate

Table 6.9 Cont'd

(h) Nitro compounds**(i) C-Nitro compounds**

4-Chloro-2,6,-dinitroaniline
 2-Chloro-3,5-dinitropyridine
 Chloronitromethane
 1-Chloro-2,4,6,-trinitrobenzene (picryl chloride)
 Dinitroacetonitrile
 2,4-Dinitroaniline
 Dinitroazomethane
 1,2-Dinitrobenzene
 1,3-Dinitrobenzene
 1,4-Dinitrobenzene
 2,4-Dinitrobenzenesulphenyl chloride
 3,5-Dinitrobenzoic acid
 3,5-Dinitrobenzoyl chloride
 2,6-Dinitrobenzyl bromide
 1,1-Dinitro-3-butene
 2,3-Dinitro-2-butene
 3,5-Dinitrochlorobenzene
 2,4-Dinitro-1-fluorobenzene
 2,6-Dinitro-4-perchlorylphenol
 2,5-Dinitrophenol
 2,4-Dinitrophenylacetyl chloride
 2,4-Dinitrophenylhydrazine
 2,4-Dinitrophenylhydrazinium perchlorate
 2,7-Dinitro-9-phenylpheanthridine
 2,4-Dinitrotoluene
 1-Fluoro-2,4-dinitrobenzene
 4-Hydroxy-3,5-dinitrobenzene arsonic acid
 1-Nitrobutane
 2-Nitrobutane
 1-Nitro-3-butene
 Nitrocellulose
 1-Nitro-3 (2,4-dinitrophenyl) urea
 Nitroethane
 2-Nitroethanol
 Nitroglycerine
 Nitromethane
 1-Nitropropane
 2-Nitropropane
 5-Nitrotetrazole
 Picric acid (2,4,6-trinitrophenol)
 Potassium 4,6,-dinitrobenzofuroxan hydroxide complex
 Potassium 3,5-dinitro-2(1-tetrazenyl) phenolate
 Potassium trinitromethanide ('Nitroform' salt)
 Sodium 5-dinitromethyltetrazolide
 Tetranitromethane
 Trichloronitromethane (chloropicrin)

2,2,4-Trimethyldecahydroquinoline picrate
 Trinitroacetonitrile
 1,3,5-Trinitrobenzene
 2,4,6-Trinitrobenzenesulphonic acid (picryl sulphonic acid)
 Trinitrobenzoic acid
 2,2,2-Trinitroethanol
 Trinitromethane
 2,4,6-Trinitrophenol (picric acid)
 2,4,6-Trinitroresorcinol
 2,4,6-Trinitrotoluene (TNT)
 2,4,6-Trinitro-*m*-xylene

(ii) N-Nitro compounds

1-Amino-3-nitroguanidine
 Azo-N-nitroformamidine
 1,2-Bis(difluoroamino)N-nitroethylamine
 N,N' Diacetyl-N,N'-dinitro-1,2-diaminoethane
 N,N' Dinitro-1,2,-diaminoethane
 N,N' Dinitro-N-methyl-1,2-diaminoethane
 1-methyl-3-nitro-1-nitrosoguanidine
 Nitric amide (nitramide)
 1-Nitro-3(2,4-dinitrophenyl) urea
 Nitroguanidine
 N-Nitromethylamine
 Nitrourea
 N,2,4,6-Tetranitro-N-methylaniline (tetryl)
 1,3,5,7-Tetranitroperhydro-1,3,5,7-tetrazocine

(iii) Ammonium nitrate**(i) Reactive vinyl monomers**

Acrylic acid
 Acrylonitrile
n-Butyl acrylate
n-Butyl methacrylate
 4-Chlorostyrene
 Divinyl benzene
 Dodecyl methacrylate
 Ethyl acrylate
 Ethylene dimethacrylate
 2-Hydroxypropyl methacrylate
 Methyl acrylate
 Methyl methacrylate
 α -Methyl styrene
 Methyl vinyl ether
 Styrene
 Vinyl acetate
 Vinyl bromide

Table 6.10 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

Table 6.11 Classification of pyrotechnics

Composition	Behaviour	Artefacts	Characteristics
Group 1			
Chlorate and metal perchlorate report or whistling compositions Dry non-gelatinized cellulose nitrates Barium peroxide/zirconium compositions	Burn very violently	Flash shells (maroons) Casings containing flash compositions Sealed hail-preventing rockets	Mass explosion risk
Group 2			
Nitrate/metal/sulphur compositions Compositions with >65% chlorate Black powder Nitrate/boron compositions	Burn violently	Large firework shells Fuse unprotected signal flares Non-pressed report bullets (bird scarers) Report cartridges (unpacked) Black matches (uncovered)	Accelerating single-item explosions
Group 3			
Nitrate/metal compositions without sulphur Compositions with ≤35–65% chlorate Compositions with black powder Lead oxide/silicon with >60% lead oxides Perchlorate/metal compositions other than report	Burn fast	Large firework shells Fuse protected signal flares Pressed report cartridges in primary packagings Quickmatches in transport packagings Waterfalls; Silver wheels; Volcanoes Black powder delays	Burn very violently with single-item explosions

Table 6.11 Cont'd

Composition	Behaviour	Artefacts	Characteristics
Group 4			
Coloured smoke compositions White smoke compositions (except those in Group 5) Compositions with <35% chlorate Thermite compositions Aluminium/phosphorus pesticide compositions	Low/medium speed burning	Large firework shells without flash compositions in transport packagings Signal ammunition without flash compositions, ≤40 g of composition Small fireworks, fuse protected (except volcanoes and silver wheels)	Single-item ignitions/ explosions
Group 5			
Slow burning/heating compositions White smoke compositions based on hexachloroethane with zinc, zinc oxide and <5% aluminium or <10% calcium silicon	Burn slowly	Small fireworks in primary packagings Signal ammunition in transport packaging Delays without black powder Coloured smoke devices Sealed table bombs White smoke devices unpackaged (see Group 5 composition)	Slow single-item ignitions/ explosions

Table 6.12 General considerations for work with explosive chemicals

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 6.15) 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 6.3), possibly with closed-circuit TV monitoring utilizing concrete outbuildings or bunkers.

Consider fire protection, detection and suppression requirements (Chapter 5), 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.

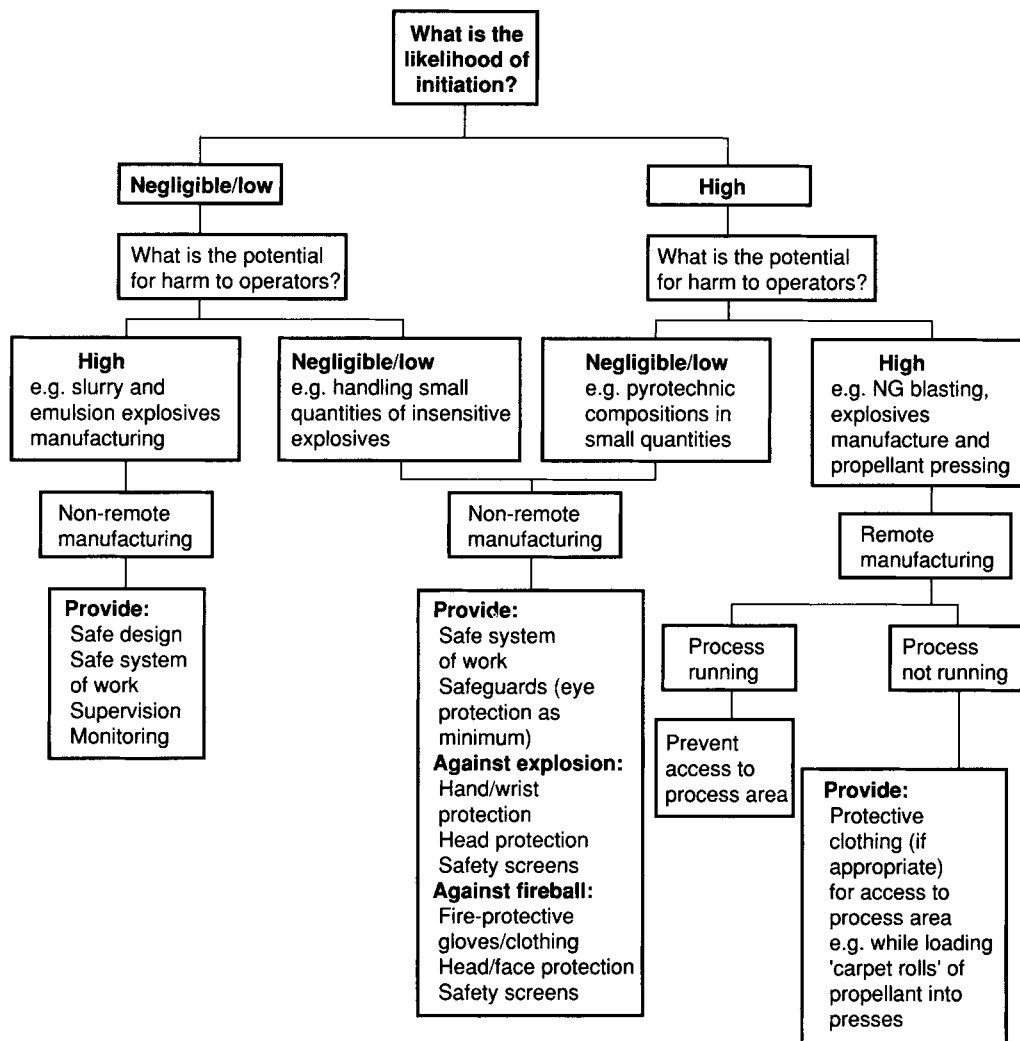


Figure 6.3 Remote versus non-remote manufacturing requirements and fire/explosion safeguards

Table 6.13 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.

Precautions

Expert advice is required before handling any of these materials, many of which are governed by a raft of legislation regulating, for instance, licensing of premises, use, storage, transportation, import/export, sale, labelling, disposal. Some general considerations are given in Table 6.12. Table 6.13 sets out basic precautions for work on a laboratory scale.

Table 6.14 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

Disposal of explosive waste and the repair or dismantling of contaminated plant need extreme care. Table 6.14 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 11); 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 protected.

Table 6.15 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 6.16. Equipment for such products requires special design and a knowledge is required of activators, decomposition rates and temperatures.

Table 6.15 Methods for testing explosives

Flame test	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.
Impact	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.
Differential scanning calorimetry Differential thermal analysis Hot stage microscope	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. 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.
Bomb calorimetry	Use of oxygen and an inert gas enables the heat of combustion and the heat of decomposition to be evaluated respectively.
Deflagration	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.

Table 6.16 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.		
Material	Trauzel lead block value (cm ³ /g)	Combustion properties
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	
2-bromo-4,6-dinitroaniline	17.5	
6-bromo-2,4-dinitroaniline	17	
2-chloro-4,6-dinitroaniline	16.5	Local decomposition – no propagation of the decomposition.
This substance exhibits a high rate of decomposition without combustion when exposed to heat and certain initiators.		
Material	Decomposition temperature	Property
P,P'-oxybis (benzenesulphonyl hydrazide)	150°C	Decomposes and propagates

Hazards arising in chemicals processing

Some factors determining chemical process hazards are summarized in Chapter 5: 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 6.17. Table 6.18 gives basic precautions in monomer storage; Table 6.19 lists properties of common monomers.

Reaction characteristics

- Reaction in gas, liquid (neat or in solution suspension/emulsion) or solid phase.
- Catalytic or non-catalytic.
- 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.

Table 6.17 Characteristics of some different types of reaction

Oxidation	Feedstocks generally hydrocarbons Hazard of fire/explosion arises from contact of flammable material with oxygen
Polymerization	Reactions highly exothermic: equilibrium favours complete reaction Exothermic reaction which, unless carefully controlled, can run-away and create a thermal explosion or vessel overpressurization Refer to Table 6.19 for common monomers Certain processes require polymerization of feedstock at high pressure, with associated hazards Many vinyl monomers (e.g. vinyl chloride, acrylonitrile) pose a chronic toxicity hazard
Halogenation	Refer to Table 6.18 for basic precautions. The commercially important halogens are chlorine, bromine, fluorine, iodine. Refer to Table 4.19 for properties All are highly toxic Reactions are highly exothermic and chain reactions can occur, which may result in detonation
Hydroprocesses	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 Main hazards: fire, explosion, metallurgical problems arising from hydrogen attack
Nitration	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 Reactions and side reactions involving oxidation are highly exothermic and may occur rapidly
Alkylation	Sensitive temperature control is essential to avoid run-away Hazards arise from the alkylating agents, e.g. dimethyl sulphate (suspected human carcinogen), hydrogen fluoride (highly toxic irritant gas) Thermal alkylation processes require higher temperatures and pressures, with associated problems
High pressure reactions	High inventories of stored pressure (e.g. in pressurized reactors or associated plant) can result in catastrophic failure of the pressure shell

Table 6.18 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
with 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

Table 6.19 Properties of common monomers

	Flash point (°C)	Ignition temp. (°C)	Flammable limits (% by vol. in air)	Specific gravity (Water = 1.0)	Vapour density (Air = 1.0)	Boiling point (°C)	Properties
Acetaldehyde (Acetic aldehyde, ethanal) CH_3CHO	-38	185	4.0-55.0	0.8	1.5	21	Colourless fuming liquid Pungent odour Irritant Water soluble Can polymerize exothermically, form explosive peroxides, or react violently with other chemicals
Acrolein Allyl aldehyde, propenal) $\text{CH}_2\text{:CHCHO}$	-26	278	2.8-31.0	0.8	1.9	53	Colourless/yellow liquid Pungent unpleasant odour Water soluble Irritant Can polymerize exothermically with strong alkalis, heat or light Can form peroxides
Acrylic acid (Propenoic acid, propene acid) $\text{CH}_2\text{:CHCOOH}$	54	—	—	1.1	2.5	140	Colourless, water soluble liquid Freezing point 14°C Polymerizes readily with oxygen Must be inhibited
Acrylonitrile (Vinyl cyanide, propenenitrile) $\text{CH}_2\text{:CHCN}$	0	481	3.0-17.0	0.8	1.8	77	Colourless, partially water soluble liquid Experimental carcinogen Polymerizes violently with organic peroxides or concentrated caustic alkalis Highly toxic Usually inhibited
1,3-Butadiene (Butadiene, vinylethylene) $\text{CH}_2\text{:CHCH:CH}_2$	-76	450	2.0-11.5	0.6	1.9	-4	Colourless, odourless liquefiable gas Polymerizes readily, particularly if O_2 or traces of catalyst present Can form explosive peroxides Normally contains inhibitor (liquid phase) and antioxidant
Epichlorhydrin (Chloropropylene oxide, epi) $\text{CH}_2\text{:OCHCH}_2\text{Cl}$	32	—	—	1.2	3.3	115	Colourless, partly water soluble liquid Highly toxic Polymerizes exothermically with acids, bases, certain salts and catalysts Can react with water
Ethyl acrylate $\text{CH}_2\text{:CHCOOC}_2\text{H}_5$	15	—	1.8- —	1.2	—	100	Colourless liquid Acrid odour Polymerizes readily, accelerated by heat, light, organic peroxides Irritant

Table 6.19 Cont'd

	Flash point (°C)	Ignition temp. (°C)	Flammable limits (% by vol. in air)	Specific gravity (Water = 1.0)	Vapour density (Air = 1.0)	Boiling point (°C)	Properties
Ethylene oxide CH ₂ :CH ₂ 	< -18	429	3.0–100	0.9	1.5	11	Colourless gas at room temperature Irritant to eyes and respiratory tract, and an experimental carcinogen Polymerizes uncontrollably with immense explosive force on contact with certain chemicals (e.g. ammonia)
Formaldehyde (Oxymethylene) HCHO	gas	430	7.0–73.0	—	1.1	–21	Colourless Water soluble gas producing formalin solutions Suffocating odour Polymerizes readily Highly toxic Respiratory sensitizer
Methacrylic acid CH ₂ :C(CH ₃)COOH	77	—	—	—	—	158	Colourless, water soluble liquid Polymerizes readily unless inhibited or stored <15°C
Methyl acrylate CH ₂ :CHCOOCH ₃	–3	—	2.8–25.0	1.0	3.0	80	Irritant Colourless liquid Acrid odour Extremely irritating to respiratory system, skin and mucous membranes
Methyl methacrylate CH ₂ :C(CH ₃)COOCH ₃	29	—	2.1–12.5	0.9	3.4	101	Colourless liquid Acrid odour
Styrene (Vinyl benzene) C ₆ H ₅ CH:CH ₂	32	490	1.1–6.1	0.9	3.6	145	Colourless/oily yellow liquid Penetrating odour Polymerizes slowly in air or light, accelerated by heat or catalysts Ignition/explosion possible Usually inhibited Store <21°C
Vinyl acetate CH ₃ COOCH:CH ₂	–8	427	2.6–13.4	1.1	3.0	72	Colourless, partially water soluble liquid Faint odour Polymerizes with heat or organic peroxides
Vinyl chloride (Chloroethene) CH ₂ :CHCl	–78	472	4.0–22.0	1.0	2.1	–14	Colourless, sweet smelling liquefiable gas Polymerizes with light, heat, air or catalysts Normally inhibited Human carcinogen
Vinylidene chloride (Dichloroethylene-1,1) CH ₂ :CCl ₂	–10	458	5.6–11.4	1.3	3.3	37	Colourless volatile liquid Polymerizes unless inhibited Decomposes at 457°C

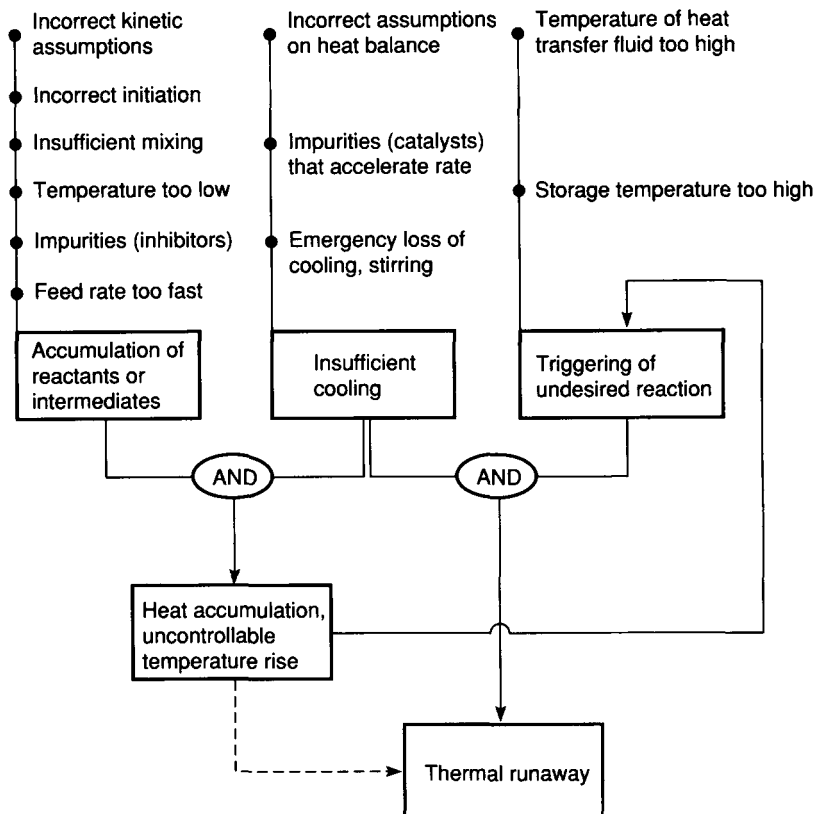


Figure 6.4 Common causes of thermal runaway in reactors or storage tanks

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 6.4. 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.

Chemical engineering operations

Many chemical engineering unit operations may be linked together in chemical processing. The commonest are:

Fluid mechanics

Pumping
Mixing
Atomization, dispersion

Heat transfer

Convective heat exchange, natural or forced
Radiation heat transfer, e.g. in furnaces
Evaporation
Condensation
Heat transfer to boiling liquids, e.g. in boilers, vaporizers, reboilers

Mass transfer operations

Distillation, either batchwise or continuous
Liquid–liquid extraction
Gas absorption/desorption, stripping, scrubbing
Humidification and water cooling
Dehumidification and air conditioning
Drying
Adsorption
Leaching, solid–liquid extraction
Crystallization

Non-mass transfer operations

Filtration
Sedimentation, gravity settling
Centrifugation
Gas cleaning
Classification by screening, sieving
Crushing, grinding

Dependent upon the chemicals in-process, each of these may introduce a range of hazard, e.g. chemical, flammable or mechanical. These must be checked in every case. Safety features which may be required are summarized in Table 6.20.

Common reaction rate v. temperature characteristics for reactions are illustrated in Figure 6.5. To avoid runaway conditions (Fig. 6.5a) or an explosion (Figure 6.5c), it may be essential to control the rate of addition of reactants and the temperature. 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:

- 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.
- Changes in reaction materials, diluents, catalysts charging procedures.
- Changes in operating conditions.

The characteristics of some potentially hazardous reactions are summarized in Tables 6.17 and 6.21.

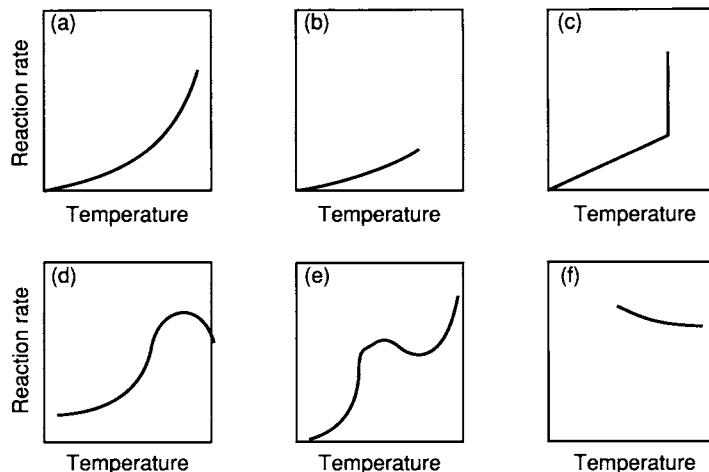


Figure 6.5 *Types of reaction rate/temperature curve*

- a Rapid increase with temperature – normal characteristic*
- b Slow increase in rate with temperature – characteristic of some heterogeneous reactions*
- c Very rapid increase at one point – the ignition point in an explosion*
- d Decrease in rate at higher temperature – characteristic of catalytic reactions*
- e Decrease in rate at intermediate temperatures, followed by an increase*
- f Slow decrease in rate with temperature*

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:

- Stirrer failure, mechanical or electrical.
- 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.
- Restricted or blocked vent.
- Leakage of *materials out*, e.g. due to a gasket failure, or *air in*.
- Attainment of abnormal reaction conditions, e.g. overpressure, over-temperature, segregation of reactants, excessive reaction rate, initiation of side reactions.
- Failure of coolant, refrigerant, or other utilities.
- Restricted material flows in or out.
- Failure of high or low pressure alarms or cut-outs.
- Power failure, affecting agitator, pumps, instruments.
- 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.
- Error in valve, switch or associated equipment operation.
- 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.
- Failure to actuate agitation at the proper time.

Table 6.20 Safety features in chemical engineering operations

Inventory	<p>Reduce inventory of chemicals:</p> <p>Continuous operation may be preferable to batch</p> <p>Low residence time contacting equipment may be better than cheaper alternatives</p> <p>etc.</p>
Monitoring	<p>Monitor temperature, pressure flow, composition, freedom from contamination and other appropriate properties of all streams where relevant</p>
Isolation	<p>Provide for isolation</p>
Contaminants	<p>Provide measures to remove unacceptable contaminants from feed materials, process streams and services</p>
Pressure	<p>Operate at moderate temperature and pressure where possible</p>
Temperature	<p>Allow for effects of over-/under-temperature, over-/under-pressure</p> <p>Provide pressure relief and explosion relief (or suppression) and systems for emergency venting where relevant</p>
Continuous flow	<p>With continuous flow operations consider (e.g. using a HAZOP procedure) the effects of:</p> <ul style="list-style-type: none"> No flow Reduced flow Reverse flow Increased flow Contaminated flow Flow of a substituted material etc.
Start-up/shutdown	<p>Provide for safe start-up, including purging if necessary</p> <p>Provide for safe shutdown:</p> <ul style="list-style-type: none"> Normal By a trip On standby In various emergency situations etc.
Instrumentation	<p>Provide safety instrumentation:</p> <ul style="list-style-type: none"> High/low temperature pressure flow level etc.
Common-mode failure	<p>linked to trips for automatic operation where appropriate</p> <p>Avoid common-mode failure possibilities with services, control systems, safety systems etc.</p>

Table 6.21 Hazard rating of chemical reactions

Reaction	Degree of hazard	Reaction	Degree of hazard
Reduction		Carbon-oxygen	
Clemmensen	D	Williamson	D
Sodium-amalgam	D	Formaldehyde - hydrochloric acid	E
Zinc-acetic acid	E	Ethylene oxide	C
Zinc-hydrochloric acid	E	Dialkyl sulphate	D
Zinc-sodium hydroxide	E	Diazoalkane	A
Ferrous ammonium sulphate	E		
Lead tetraacetate	E	Carbon-nitrogen	
Meerwein-Pondorff	D	Cyanomethylation	C
Lithium aluminium hydride	B	Chloromethylation	D
Dialkyl aluminium hydride	B	Ethylenimine	C
Rosenmund	A	Ethylene oxide	C
Catalytic high pressure	A	Quaternization	D
Catalytic low pressure	B		
Oxidation		Condensation	
Hydrogen peroxide - dilute aqueous	E	Erlenmeyer	D
Air or I ₂ (mercaptan to disulphide)	D	Perkin	D
Oppenauer	D	Acetoacetic ester	D
Selenium dioxide	D	Aldol	D
Aqueous solution nitric acid, permanganate, manganic dioxide, chromic acid, dichromate	E	Claisen	D
Electrolytic	B	Knoevenagel	D
Chromyl chloride	C	Condensations using catalysts such as phosphoric acid; AlCl ₃ ; KHSO ₄ ; SnCl ₄ ; H ₂ SO ₄ ; ZnCl ₂ NaHSO ₂ ; POCl ₂ ; HCl; FeCl ₂	E
Ozonolysis	A	Acyloin	C
Nitrous acids	A	Diketones with hydrogen sulphide	C
Peracids - low molecular weight or two or more positive groups	A	Diketones with diamines → quinazolines	D
Peracids - high molecular weight	B	Diketones with NH ₂ OH → isoxazolines	D
<i>t</i> -Butyl hypochlorite	C	Diketones with NH ₂ NH ₂ → pyrazoles	C
Chlorine	C	Diketones with semicarbazide → pyrazoles	D
Alkylation		Diketones with ammonia → pyrazoles	D
Carbon-carbon		Carbon disulphide with aminoacetamide → thiazolone	A
Jarousse	E	Nitriles and ethylene diamines → imidazolines	D
Alkali metal	C		
Alkali metal alcoholate	D	Amination	
Alkali metal amides and hydrides	C	Liquid ammonia	B
Reformatsky	E	Aqueous ammonia	E
Michael	E	Alkali amides	C
Grignard	B		
Organometallics, such as dialkyl zinc or cadmium-alkyl or aryl lithium	B		
Alkali acetylides	A		
Diels-Alder	D		
Arndt-Eistert	A		
Diazoalkane and aldehyde	A		
Aldehydes or ketones and hydrogen cyanide	C		

Table 6.21 Cont'd

<i>Reaction</i>	<i>Degree of hazard</i>	<i>Reaction</i>	<i>Degree of hazard</i>
Esterification		Simple metathetical replacement	D
Inorganic	E		
Alkoxy magnesium halides	B	Preparation and reaction of peroxides and peracids	
Organic:		Concentrated	A
Alcohol and acids or acid chloride or acid anhydride	D	Dilute	D
Alkyl halide and silver salts of acids	E	Pyrolysis	
Alkyl sulphate and alkali metal salt of acid	D	Atmospheric pressure	D
Alkyl chlorosulphates and alkali salts of carboxylic acid	D	Pressure	B
Ester-exchange	D	Schmidt reaction	B
Carboxylic acid and diazomethane	A	Mannich reaction	D
Acetylene and carboxylic acid-vinyl ester	A	Halogenation	
Hydrolysis, aqueous nitriles, esters	E	SO ₂ X ₂ , SOX ₂ , SX, POX ₂ , PX ₅	D
		HX	D
		Cl ₂ , Br ₂	C
		Nitration	
		Dilute	D
		Concentrated	B
Hazardous		Conventional	
A Highly flammable		D Slightly flammable	
Develops high pressure instantly		Generates or uses mildly toxic substances	
Highly toxic		E Non-flammable	
Special		Does not use or generate toxic substances	
B Flammable, perhaps explosive, mixtures form			
C Flammable, or generates toxic substances			

Cryogenics

Cryogenics, or low-temperature technology, generally relates to temperatures below about -73°C (as distinguished from refrigeration). Applications can be found in food processing, rocket propulsion, microbiology, electronics, medicine, metal working and general laboratory operations. Such low temperatures are primarily achieved by the liquefaction of gases as exemplified by Table 7.1. Every gas has a critical temperature above which it cannot be liquefied by application of pressure alone (Chapter 3). As a result, gases used, e.g., as an inert medium to reduce oxygen content of atmospheres containing flammable gas or vapour (Chapter 5), are often shipped and stored as cryogenic liquid for convenience and economy.

Table 7.1 Properties of common cryogenics

Gas	Boiling point ($^{\circ}\text{C}$)	Volume of gas produced on evaporation of 1 litre of liquid (litres)
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

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 7.2. Unless strict handling precautions are instituted, it is advisable to replace the more toxic and flammable solvents by safer alternatives.

The main hazards with cryogenics 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.

Table 7.2 Working temperatures of cryogenic slush baths

<i>Bath liquid</i>	<i>Temperature (°C)</i>
Carbon tetrachloride	–23
Chlorobenzene	–45
Solid carbon dioxide	–63
in acetone or methylated spirits ⁽¹⁾	–78
Toluene	–95
Carbon disulphide	–112
Diethyl ether	–120
Petroleum ether	–140

⁽¹⁾ Liquid nitrogen is omitted from this mixture and the solvent is used to improve the heat transfer characteristics of cardice.

- 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), toxicity (e.g. carbon dioxide, fluorine), or chemical reactivity (fluorine, oxygen).

Key precautions are given in Table 7.3.

The cryogenics encountered in greatest volume include oxygen, nitrogen, argon and carbon dioxide. Their physical properties are summarized in Table 7.4.

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.

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 7.3, 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 water spray unless electrical equipment is involved, when carbon dioxide extinguishers should be used.

Table 7.3 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 5). 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 11).

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 11).

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.

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

Table 7.4 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 (at atmospheric pressure)	°C	−183	−196	−186	−78
Freezing point	°C	−219	−210	−190	—
Density of liquid (at atmospheric pressure)	kg/m ³	1141	807	1394	1562 (solid)
Density of vapour (at NBP)	kg/m ³	4.43	4.59	5.70	2.90
Density of dry gas at 15°C and at atmospheric pressure	kg/m ³	1.34	1.17	1.67	1.86
Latent heat of vaporization at NBP and atmospheric pressure	kJ/kg	214	199	163	151
Expansion ratio (liquid to gas at 15°C and atmospheric pressure)		842	682	822	538 ⁽¹⁾
Volume per cent in dry air	%	20.95	78.09	0.93	0.03

NBP Normal boiling point

⁽¹⁾ From liquid CO₂ at 21 bar −18°C.

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 4). 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

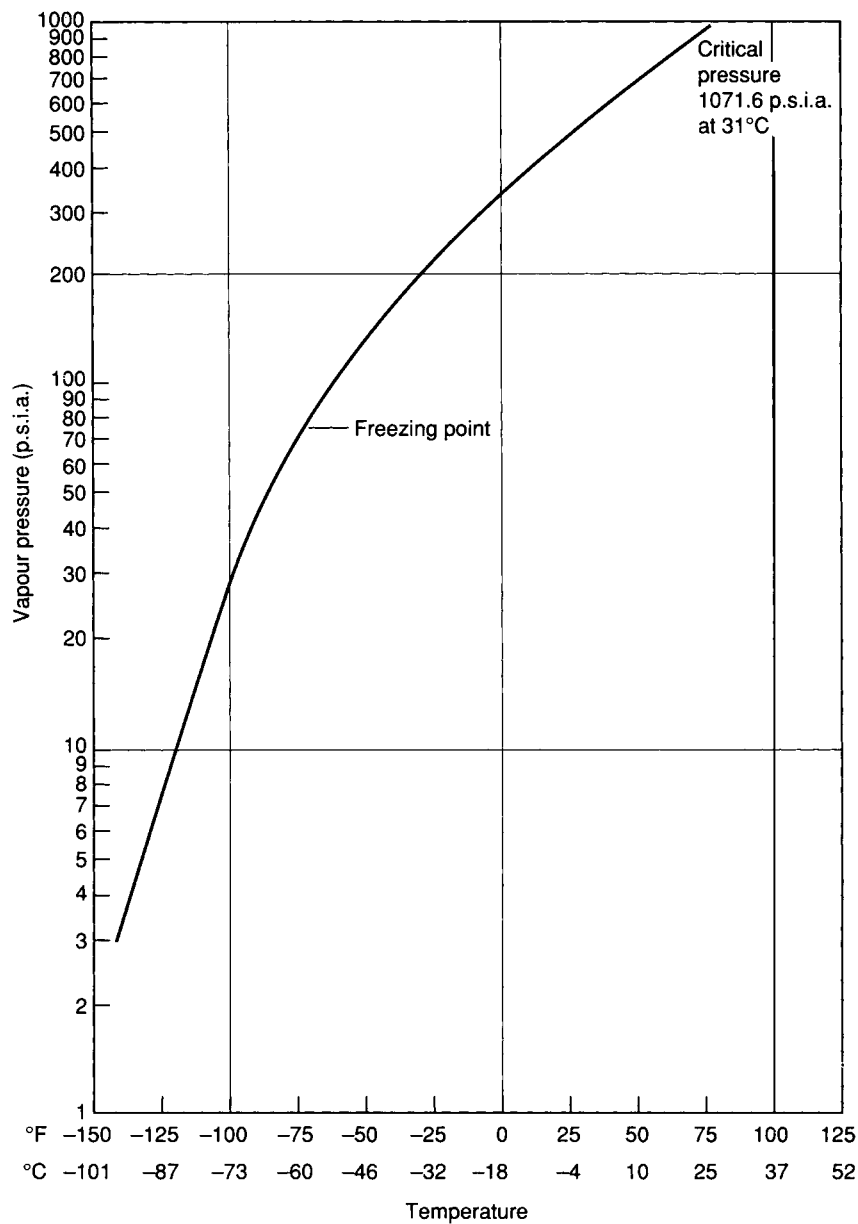


Figure 7.1 Carbon dioxide vapour pressure versus temperature

slightly pungent odour and characteristic acid 'taste'. Physical properties are given in Table 7.5. Figure 7.1 demonstrates the effect of temperature on vapour pressure.

Inhalation of carbon dioxide causes the breathing rate to increase (Table 7.6): 10% CO₂ 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 4) for carbon dioxide is 0.5%; at higher

Table 7.5 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, 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 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	3.5×10^{-5} cal/scm ² °C/cm
at 100°C	5.5×10^{-5} cal/scm ² °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

levels life may be threatened by extended exposure. The following considerations therefore supplement those listed in Table 7.3:

- Ensure that operator exposure is below the hygiene standard. (Note: For environmental monitoring, because of its toxicity, a CO₂ 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.

Table 7.6 Effect of carbon dioxide exposure on breathing rates

CO ₂ in air (vol. %)	Increased lung ventilation
0.1–1	slight, unnoticeable
2	50% increase
3	100% increase
5	300% increase; breathing becomes laborious

Compressed gases

Gases are often stored at low pressure, either under refrigerated conditions, e.g. cryogenics (Chapter 7), 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 the contents, ease of diffusion of escaping gas, low flashpoint of highly flammable materials, and the absence of visual and/or odour detection of 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 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.

Precautions also have to be instituted to protect against the inherent properties of the cylinder contents, e.g. toxic, corrosive, flammable (refer to Table 8.1). 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 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.

To prevent interchange of fittings between cylinders of combustible and non-combustible gases, the valve outlets are screwed left-hand thread and right-hand, respectively (Table

Table 8.1 Compressed gases: hazards and construction materials for services

Gas	Hazard ⁽¹⁾			Materials of construction for ancillary services ⁽²⁾	
				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, copper 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 Copper, Monel, Hastelloy B, PVC polythene and PTFE if moist 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 dry gas ≤200°C. Borosilicate glass for low pressures. For moist 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. 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 8.1 Cont'd

Gas	Hazard ⁽¹⁾			Materials of construction for ancillary services ⁽²⁾	
				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 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	

Table 8.1 cont'd

Gas	Hazard ⁽¹⁾	Materials of construction for ancillary services ⁽²⁾	
		Compatible	Incompatible
Ethyl acetylene	F	Steel and stainless steel	Copper other metals capable of forming explosive acetylides
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

Table 8.1 Cont'd

Gas	Hazard ⁽¹⁾		Materials of construction for ancillary services ⁽²⁾	
			Compatible	Incompatible
Hydrogen iodide	C	T	Stainless steel, mild steel under normal temperature and pressure 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	Moist gas corrodes most metals 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			Most common metals	Copper, silver, mercury and their alloys
Methylamine	C	F T	Iron and steel	
Methyl bromide	C	F T	Most common metals when dry	Copper, tin, zinc and their alloys. Avoid mercury 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

Table 8.1 Cont'd

Gas	Hazard ⁽¹⁾			Materials of construction for ancillary services ⁽²⁾	
				Compatible	Incompatible
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	Avoid the metals opposite
octofluorocyclobutane		T		Cast iron and stainless steel <120°C, steel ≤175°C, Inconel, nickel and platinum ≤400°C	>500°C
Oxygen			O	Most common metals	On grease or combustible materials
Oxygen difluoride		T	O	Glass, stainless steel, copper, Monel or nickel ≤200°C. At higher temperatures only nickel and Monel are recommended	
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 At higher temperatures many organic materials and some metals can be ignited Some metals such as titanium show deflagration in contact with the gas under severe shock
Perfluorobutane				Most common materials	
Perfluorobutene			T	Most common materials when dry	
Perfluoropropane				Most common metals	
Phosgene	C		T	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	

Table 8.1 Cont'd

Gas	Hazard ⁽¹⁾			Materials of construction for ancillary services ⁽²⁾	
				Compatible	Incompatible
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	
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

⁽¹⁾ 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.

⁽²⁾ This is a guide and is no substitute for detailed literature.

Table 8.2 Colour codes for common compressed gases

<i>Gas</i>	<i>Colour</i>	<i>Thread</i>
Acetylene	Maroon	LH
Air (not for breathing)	Grey	LH
Chlorine	Yellow	RH
Hydrogen	Red	LH
Methane	Red with green band on shoulder	LH
Methyl chloride	Green with red neck	RH
Natural gas	Red with green band on shoulder	LH
Nitrogen	Grey with black neck	RH
Oxygen	Black	RH
Sulphur dioxide	Green with yellow neck	RH

8.2). 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 and colour bands on the cylinder shoulder to denote the nature of the gas, as exemplified by Table 8.2 for selected common gases. (The full scheme is given in BS 349: 1973.)

Table 8.3 provides general guidance for handling compressed gases. Selected common, hazardous compressed gases are discussed below.

Table 8.3 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 CO₂. 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 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.

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 jointing 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.

Acetylene

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 tetrachloro-ethylene 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. Its physical properties are shown in Table 8.4.

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

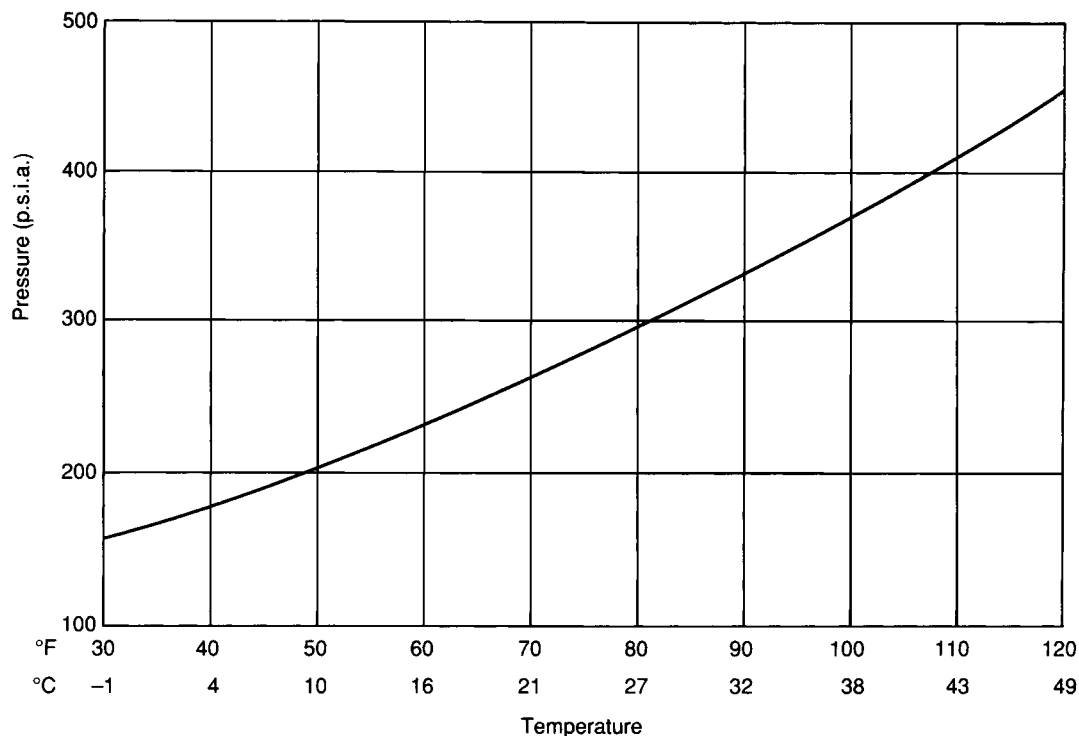


Figure 8.1 *Acetylene (in acetone): full cylinder pressure versus temperature.*

Table 8.4 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	4.8×10^{-5} cal/s cm ² °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 ₂ O

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.

Figure 8.1 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, e.g. 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 8.3, 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.

Ammonia

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 8.5. The effect of temperature on vapour pressure of anhydrous ammonia is shown in Figure 8.2.

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.

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 8.6 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%.

Besides the control measures given in Table 8.3, 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.
- Use under well-ventilated conditions and provide convenient safety showers and eye-wash facilities.

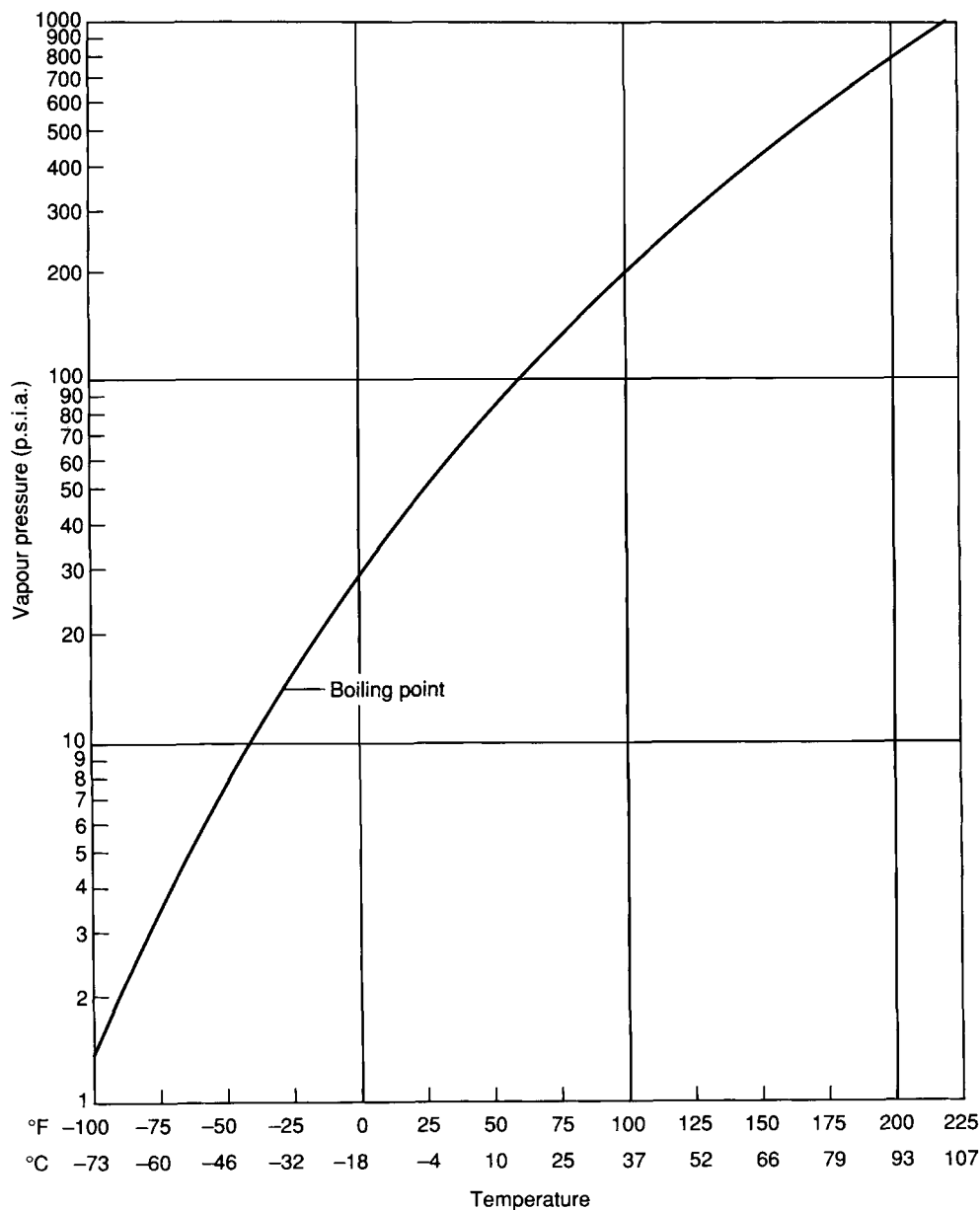


Figure 8.2 Ammonia vapour pressure versus temperature

- 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 8.7).

Table 8.5 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 K
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	5.22×10^{-5} cal/s cm ² °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

Table 8.6 Physiological effects of ammonia

<i>Atmospheric concentration (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

Chlorine

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

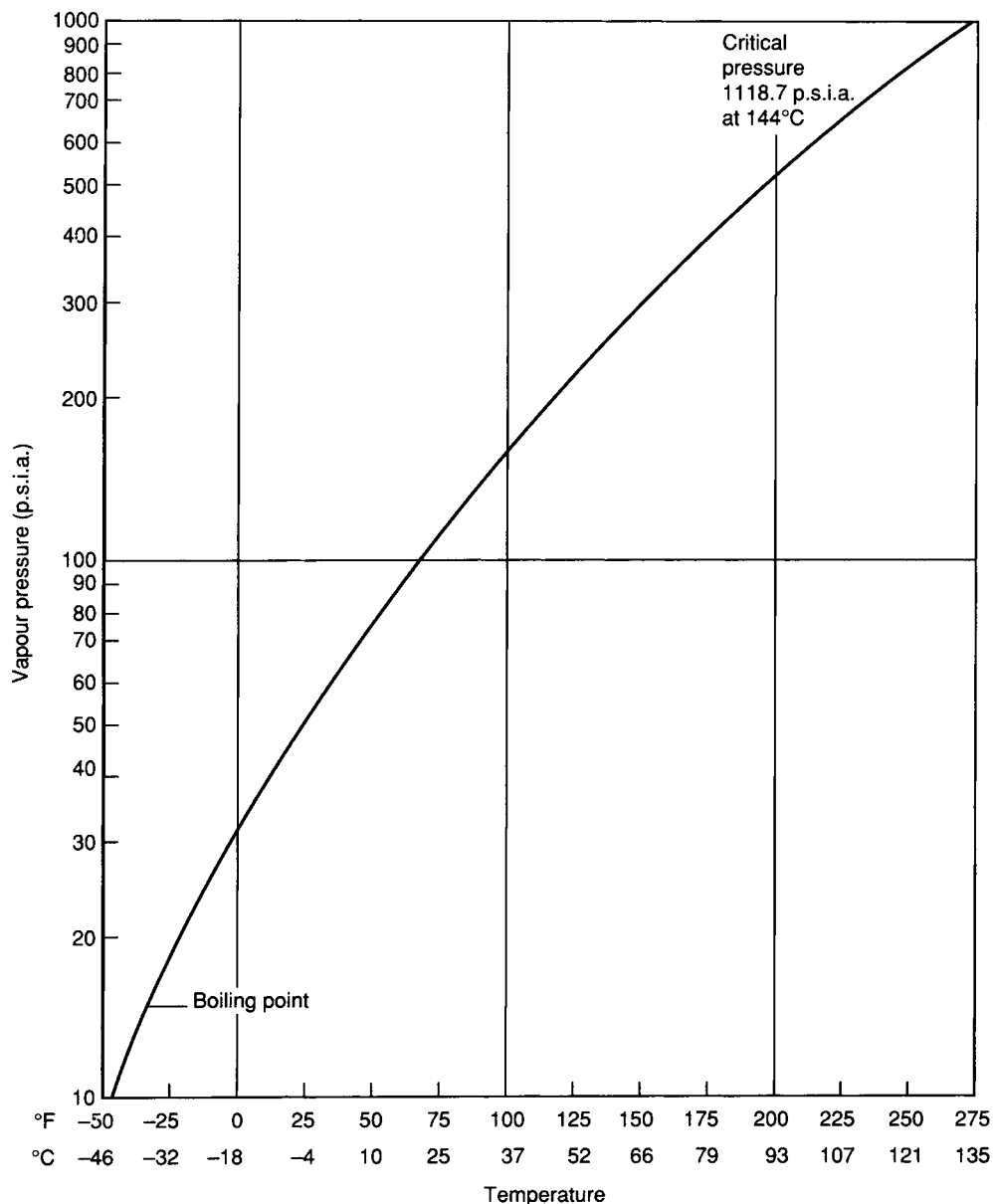


Figure 8.3 Chlorine vapour pressure versus temperature

irritant. Persons exposed to chlorine become restless, sneeze, develop sore throat and salivate copiously. Effects on the body are summarized in Table 8.8 and physical characteristics are given in Table 8.9.

Moist chlorine is corrosive to skin and to most common materials of construction. Wet chlorine at low pressure can be handled in chemical stonewear, glass or porcelain and in certain alloys and plastics.

The effect of temperature on vapour pressure is shown in Figure 8.3. Cylinders are normally protected from over-pressurization by a fusible metal plug melting at about 85°C.

The following safety measures supplement the general precautions listed in Table 8.3:

- 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.

Table 8.7 First aid measures following exposure to a compressed gas

Obtain medical help immediately	
Inhalation	Remove victim to uncontaminated area and carry out artificial respiration In the case of hydrogen sulphide, ensure that the patient remains rested and refrains from exercise for 24 hr For chlorine gassing, lay victim on stomach with head and shoulders slightly lowered; discourage from coughing
Skin contact	Use emergency shower, removing contaminated clothing and shoes at the same time
Eye contact	Wash promptly with copious amounts of water for ≥ 15 min

Table 8.8 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 8.9 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	1.8×10^{-5} cal/s cm ² °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

- 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 8.7 (refer also to Table 11.17).

Table 8.10 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)	0.069 52
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	0.031 36 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	0.000 40 cal/s cm ² °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 ₂ O

Hydrogen

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 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 8.10.

The main danger with hydrogen is of fire or explosion. The following precautions are important to supplement those in Table 8.3:

- Use only in well-ventilated conditions to avoid accumulation at high levels.
- Eliminate means of accidental ignition.
- Use only explosion-proof 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 sulphide

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. Physical properties are summarized in Table 8.11 and effects of temperature on vapour pressure are shown in Figure 8.4.

Hydrogen sulphide is a dense, colourless, highly flammable water-soluble gas with

Table 8.11 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	3.05×10^{-5} cal/s cm ² °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	0.011 66 cP

an offensive odour of rotten eggs. It is highly toxic; its effects on the body are given in Table 4.25. Acute poisoning may result from exposures at or above 700 ppm due to systemic effects, including attack on the nervous system and respiratory collapse.

Cylinders are typically protected from over-pressurization by frangible gold-plated discs and fusible plugs.

Important precautions include:

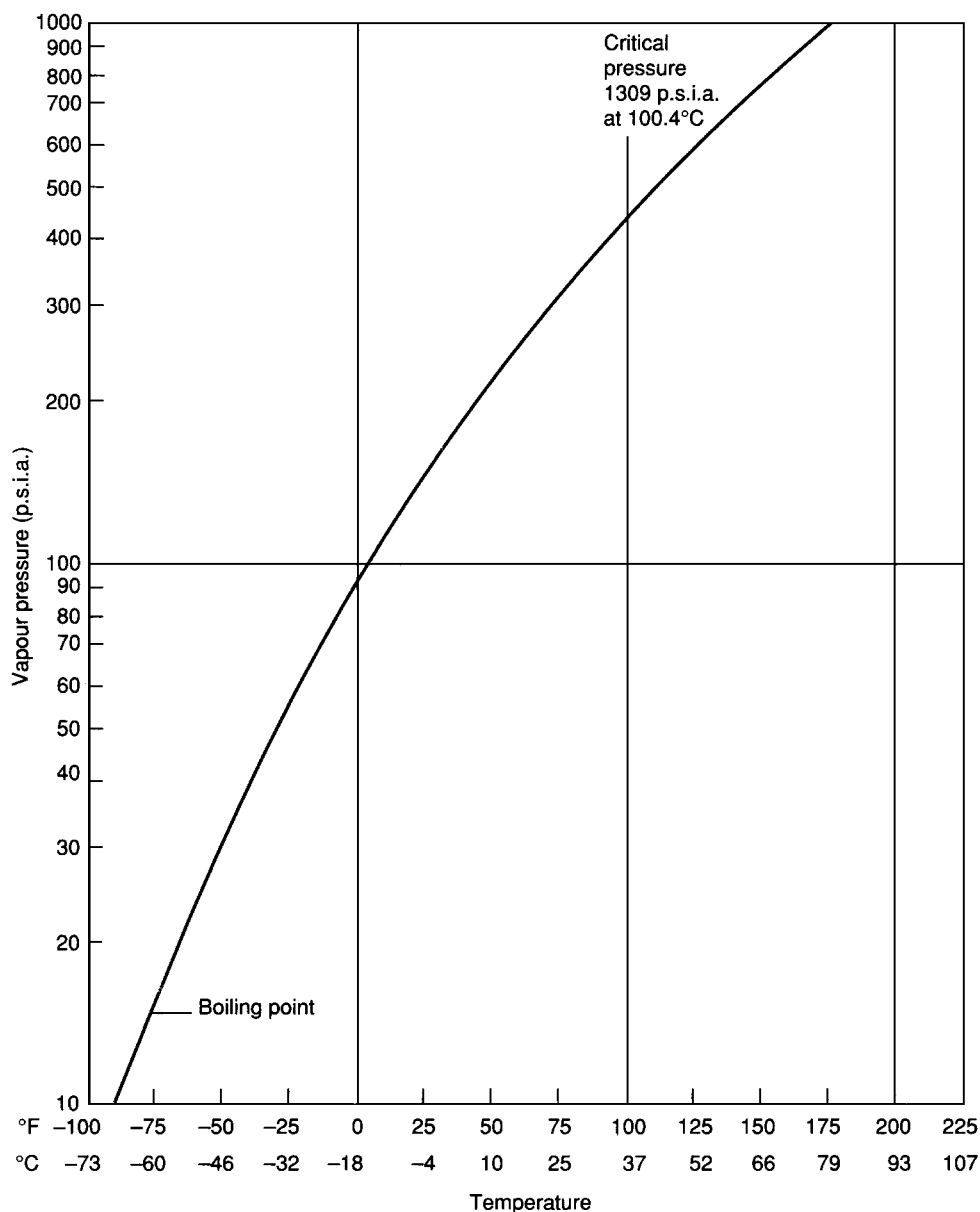


Figure 8.4 Hydrogen sulphide vapour pressure versus temperature

- 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.
- 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 8.7.

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 8.5 depicts the effect of temperature on vapour pressure; Table 8.12 lists the physical properties. Cylinders tend to be protected against over-pressurization by metal plugs melting at about 85°C.

Table 8.12 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	2.06×10^{-5} cal/s cm ² °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

Gaseous sulphur dioxide is highly irritant and practically irrespirable. Effects on the body are summarized in Table 4.3. It can be detected at about 3.5 ppm and the irritating effects would 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

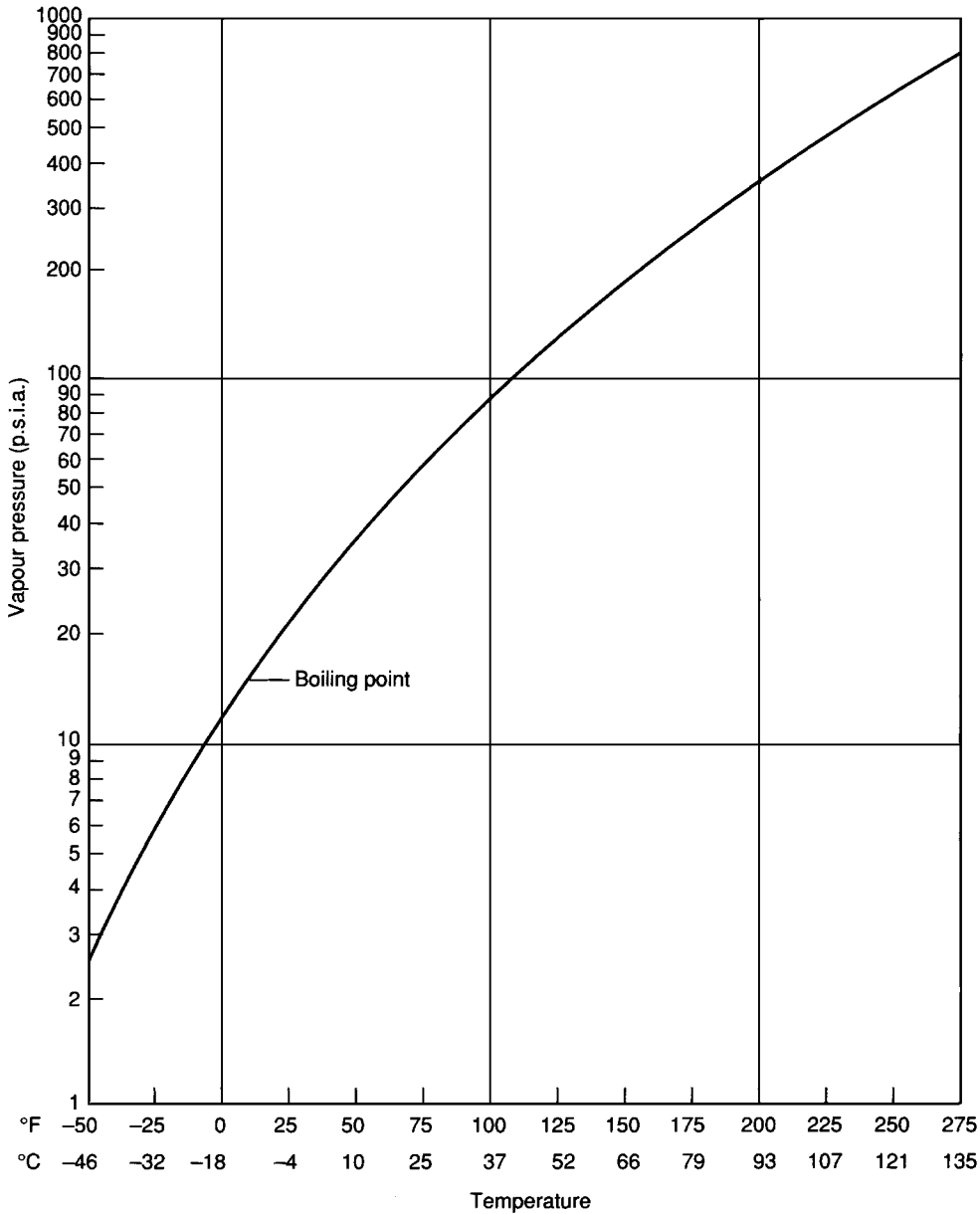


Figure 8.5 Sulphur dioxide vapour pressure versus temperature

construction except zinc. The presence of moisture renders the environment corrosive.

In addition to the precautions listed in Table 8.3, the following controls are appropriate:

- Use in well-ventilated areas.
- 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 8.7.

Monitoring techniques

As discussed in Chapter 4, chemicals can be a nuisance or pose health risks if they become airborne as a result of inadequate process control, operation and maintenance malpractice, inadequate maintenance, incomplete understanding of the process etc. Hazards may arise if the oxygen concentration in the air fluctuates beyond its normal level of 21% by volume, and fire/explosion dangers may arise from the presence of flammable gases, vapours or dusts in the atmosphere. Thus air quality tests may be required for a variety of purposes such as:

- Assessing risk from atmospheres containing flammable gas or vapour.
- Determining oxygen content.
- Detecting sources of leaks of toxic or flammable pollutants.
- Identifying unknown pollutants.
- Determining employee exposure to known toxic substances.
- Assessing performance efficiency of engineering control measures.
- Complying with legislation.

Monitoring techniques include sophisticated in-line continuous monitoring linked to audible/visual alarms, background monitors running continuously throughout the working day, grab sampling (i.e. samples collected over a short time-span, e.g. a few minutes) and personal dosimetry (when collection devices are worn by operators to sample the air wherever they may be throughout the work period).

Environmental analysis entails sampling ambient air (Table 9.1) by means of a pump with subsequent analysis of the collected sample. Pumps vary from large, stationary high-volume versions to pocket-size devices used in personal dosimetry. Samples may be collected in airtight bags, or absorbed in liquids or on solid adsorbents for subsequent analysis.

A common approach for personal dosimetry is collection of pollutant on, e.g., silica gel, organic resins or activated charcoal in small tubes worn on the operator's lapel (Table 9.2). Silica gel is useful for polar chemicals; charcoal finds wide use for non-polar substances. The pollutant is then solvent-extracted or thermally desorbed for subsequent analysis by, e.g., chromatography.

Advantages and disadvantages of thermal desorption are listed in Table 9.3. (Charcoal 'badges' are also available which require no pump; these are termed 'passive samplers'.) Instruments are also available to give direct readout of atmospheric levels of pollutant.

The range of analytical techniques is extensive and usually requires the help of a hygienist. The following illustrates a selection of common techniques.

Table 9.1 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 Wash bottle Drechsel bottle 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 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 Fumes require very slow rates.
Gases or vapours of all types Mists	Absorption with multiple contact provided by wetted surfaces	Packed columns of glass beads, glass spirals, or fibres Plastic packing also feasible in some cases Large surface wall area units also included	Water, acid, alkali, or organic solvents	1–5	90–100	May incorporate device for continually wetting column 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 venturi scrubber	Water, acid, or alkali	5–25	60–100	Venturi scrubber satisfactory if dust is present 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 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 9.2 Charcoal tube user guide

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	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 ₂
	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 ₂
	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 ₂
	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 ₂
	1–20	3.1–62.6	100	100	50			
Benzyl chloride	0.05–2	0.25–10	—	200	200	>0.4	90 ± 5	CS ₂
Bromoform	0.05–1	0.5–10	200	100	50	>0.25		CS ₂
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 ₂
	25–300	118–1420	50	25	10			
sec-Butyl acetate	1–50	4.8–237.5	100	100	50	15	91 ± 5	CS ₂
	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 ₂
	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			

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
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 ₂
	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 ₂
	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 ₂
	2–20	13–130	200	100	50			
Chlorobenzene	0.75–10	3.5–23.3	100	100	50	15.5	90 ± 5	CS ₂
	10–150	23.3–700	50	25	10			
Chlorobromomethane	2–20	10.5–105	100	50	25	9.3	94 ± 5	CS ₂
	20–400	105–2100	25	10	5			
Chloroform	0.5–10	2.4–48	200	100	50	11	96 ± 5	CS ₂
	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 ₂
	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 ₂
	10–100	49–490	50	25	10			
Cyclohexane	3–50	10.5–175	100	50	25	6.3	100+	CS ₂
	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 ₂
	10–100	40–400	100	50	25			
Cyclohexene	3–50	10.2–169.2	100	50	25		100+	CS ₂
	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 ₂
	10–100	60–600	50	25	10			
<i>p</i> -Dichlorobenzene	1–25	6–150	100	100	50		85 ± 5	CS ₂
	25–150	150–900	50	25	10			

Table 9.2 cont'd

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
Dichlorodifluoromethane (Freon 12)	5–100 100–2000	24.8–495 495–9900	100 10	50 5	25 1			
1,1-Dichloroethane	1–15 15–200	4–60 60–300	100 50	100 25	50 10	7.5	100+	CS ₂
1,2-Dichloroethylene	2–25 25–400	7.9–99 99–1580	100 25	50 10	25 5	5.1	100+	CS ₂
1,1-Dichloro-1-nitroethane	0.1–1.5 1.5–20	0.6–9 9–120	200 100	200 50	100 25	9		CS ₂
Dichloroethyl ether	0.5–5 5–30	3–30 30–180	200 100	100 50	50 25			
Dichloromonofluoromethane (Freon 21)	5–100 100–2000	21–420 420–8400	100 10	50 5	25 1			
Dichlorotetrafluoroethane	5–100 100–2000	35–700 7000–14 000	50 5	25 1	10 1			
Difluorodibromomethane	1–15 15–200	8.6–129 129–1720	100 25	50 10	25 5	15		CS ₂
Diisobutyl ketone	0.5–7.5 7.5–100	2.9–43.5 43.5–580	200 100	100 50	50 25	12.5		CS ₂
Dimethylaniline	0.1–1 1–10	0.5–5 5–50	200 100	200 50	100 25	>1.1	>80	CS ₂
Dimethylformamide	0.5–4 2–20	1.5–12 6–60	200 100	100 100	50 50			
f-Dioxane	1–15 15–200	3.6–54 54–720	200 100	100 50	50 25	13	91 ± 5	CS ₂
Dipropylene glycol methyl ether	1–15 15–200	6–90 90–1200	100 25	50 10	25 5		75 ± 15	CS ₂
Epichlorohydrin	0.1–1 1–10	0.4–4 4–40	— 100	200 50	100 25	>1	>80	CS ₂
2-Ethoxyethanol	2–30 30–400	7.4–111 111–1480	100 50	50 25	25 10			
2-Ethoxyethyl acetate	1–15 15–200	5.4–81 81–1080	200 50	100 25	50 10	19	74 ± 10	CS ₂
Ethyl acetate	5–75 75–800	17.5–263 263–2800	100 25	50 10	25 5	12.5	90 ± 10	CS ₂
Ethyl acrylate	0.5–5 5–50	2–20 20–200	200 200	200 100	100 50	<5	95 ± 5	CS ₂
Ethyl alcohol	5–100 100–2000	9.4–188.5 188.5–3770	100 5	50 1	25 1	2.6	77 ± 10	5
Ethyl benzene	1–15 15–200	4.4–65.3 65.3–870	200 100	100 50	50 25	16	100+	CS ₂

Table 9.2 Cont'd

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
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 ₂
	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 ₂
	15–200	45–600	50	25	10			
Ethylene chlorohydrin ⁽⁶⁾	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 ₂
	2–40	15.5–310	100	50	25			
Ethylene dichloride	0.5–10	2–40.5	200	200	100	12	95 ± 5	CS ₂
	10–100	40.5–405	100	50	25			
Ethylene oxide	0.5–10	0.9–18	200	100	50	1.1		CS ₂
	10–100	18–180	100	50	25			
Fluorotrichloromethane (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 ₂
	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 ₂
	100–1000	400–4000	10	5	1			
Hexachloroethane	0.05–2	0.5–20	200	200	100		98 ± 5	CS ₂
Hexane	5–100	18–360	100	50	25	11	94 ± 5	CS ₂
	100–1000	360–3600	10	5	1			
Isoamyl acetate	1–15	5.3–78.8	200	100	50	16.5	90 ± 5	CS ₂
	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 ₂
	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 ₂
	5–50	28–280	50	25	10			
Isopropyl acetate	2–50	7.6–190	100	100	50	13	85 ± 5	CS ₂
	50–500	190–1900	25	10	5			
Isopropyl alcohol	5–75	12.3–185	100	50	25	5.6	94 ± 5	5

Table 9.2 Cont'd

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
Isopropyl ether	75–800	185–1970	25	10	5			
	5–100	21–420	100	50	25			
	100–1000	420–4200	10	5	1			
Isopropyl glycidyl ether	0.5–10	2.4–48	200	100	50	10.5	80 ± 10	CS ₂
	10–100	48–480	100	50	25			
Mesityl oxide	0.5–10	2–40	200	200	100	4.8	79 ± 5	1
	5–50	20–200	100	50	25			
Methyl acetate	1–50	3.1–152.5	200	100	50	7	88 ± 5	CS ₂
	50–400	152.5–1220	25	10	5			
Methyl acrylate	0.1–2	0.35–7	—	200	100	>1.5	80 ± 10	CS ₂
	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 ₂
	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 ₂
	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 ₂
	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 ₂
	5–50	24–240	100	50	25			
Methyl chloride	1–15	2.1–31.5	200	100	50	1		CS ₂
	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 ₂
	75–700	407–3800	25	10	5			
Methyl cyclohexane	5–100	20–400	100	50	25		95 ± 5	CS ₂
	100–1000	400–4000	10	5	1			
Methyl ethyl ketone (2-butanone)	2–50	5.9–148	100	100	50	9.5	89 ± 10	CS ₂
	50–400	148–1180	50	25	10			
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			

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
Methyl iodide	0.1–1 1–10	0.56–5.6 5.6–56	200 100	200 50	100 25	7		14
Methyl isobutyl carbinol	0.5–5 5–50	2.1–21 21–210	200 200	100 100	50 50	5.7	99 ± 5	2
Methyl isoamylacetate	1–10 10–100	6–60 60–600	200 100	100 50	50 25	14		CS ₂
α-methyl styrene	1–15 15–200	4.8–72 72–960	200 100	200 50	100 25	21	91 ± 5	CS ₂
Methylene chloride	5–75 75–1000	17.4–261 261–3480	100 10	100 5	50 1	9.3	95 ± 10	CS ₂
Naphtha (coal tar)	1–15 15–200	4–60 60–800	200 100	100 50	50 25	14.8	88 ± 5	CS ₂
Naphthalene	0.1–2 1–20	0.5–10 5–100	200 100	200 50	100 25			
Nitromethane	1–15 15–200	3.1–46.5 46.5–620	200 50	200 25	100 10			
1-Nitropropane	0.5–10 5–50	1.8–36 18–180	200 100	100 50	50 25			
2-Nitropropane	0.5–10 5–50	1.8–36 18–180	200 100	100 50	50 25			
Nonane	2–30 30–400	10.5–157.5 157.5–2100	100 25	50 10	25 5			CS ₂
n-Octane	5–75 75–1000	23.5–352 352–4700	100 10	50 5	25 1	15	93 ± 5	CS ₂
Pentane	5–100 100–2000	15–295 295–5900	200 10	100 5	50 1	9	96 ± 5	CS ₂
2-Pentanone	1–75 75–400	3.5–263 263–1400	200 25	100 10	50 5		88 ± 5	CS ₂
Perchloroethylene (tetrachloroethylene)	1–15 15–200	6.8–102 102–1362	200 50	100 25	50 10	29	95 ± 5	CS ₂
Petroleum distillates	5–75 75–1000	20–300 300–4000	100 10	50 5	25 1	12.3	96 ± 5	CS ₂
Phenol	0.1–2 1–10	0.38–7.6 3.8–38	— 200	200 100	100 50			
Phenyl ether (vapour)	0.05–2	0.35–14	—	200	200	0.6	90 ± 5	CS ₂
Phenyl glycidyl ether	0.5–4 2–20	3–24 12–120	200 100	100 50	50 25	12.5	97 ± 5	CS ₂
n-Propyl acetate	1–75 75–400	4.2–315 315–1680	200 50	100 25	50 10	14.5	93 ± 5	CS ₂
n-Propyl alcohol	1–75 75–400	2.5–184 184–980	200 50	100 25	50 10	9	87 ± 5	3
Propylene dichloride	1–15 15–150	4.6–70 70–700	200 50	100 25	50 10	5	97 ± 5	CS ₂
Propylene oxide	1–15 15–200	2.4–36 36–480	200 25	100 10	50 5	2	90 ± 5	CS ₂

Table 9.2 Cont'd

Substance	Expected concentration range ⁽¹⁾		Recommended sampling ⁽²⁾ (ml/min)			Recommended maximum tube load ⁽³⁾ (mg)	Approximate desorption efficiency ⁽⁴⁾ (%)	Eluent ⁽⁵⁾
	(ppm)	(mg/m ³)	2 hr	4 hr	8 hr			
<i>n</i> -Propyl nitrate	0.5–5	2.2–22	200	100	50	12		CS ₂
	5–50	22–220	100	50	25			
Pyridine	0.5–2	1.5–6	200	200	100	>7.3	70 ± 10	CS ₂
	1–10	3–30	200	100	50			
Stoddard solvent	5–75	29.5–443	100	50	25	13	96 ± 5	CS ₂
	75–1000	443–5900	10	5	1			
Styrene (monomer)	1–15	4.3–64	200	100	50	18	87 ± 5	CS ₂
	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 ₂
	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 ₂
	75–1000	625–8340	10	5	1			
1,1,2,2-Tetrachloroethane ⁽⁶⁾	0.1–2	0.7–14	200	200	100	4.5	85 ± 5	CS ₂
	1–10	7–70	100	100	50			
Tetrahydrofuran	1–75	2.5–184	200	100	50	7.5	92 ± 5	CS ₂
	75–400	184–1180	25	10	5			
Tetramethyl succinonitrile	0.05–1	0.3–6	—	200	200	>0.8		CS ₂
Toluene	1–15	3.8–56	200	100	50		92 ± 5	CS ₂
	15–200	56–750	50	25	10			
1,1,2-trichloroethane	0.1–2	0.6–11	200	100	50	5	96 ± 5	CS ₂
	2–20	11–110	100	50	25			
Trichloroethylene	1–15	5.4–80	200	100	50	21	96 ± 5	CS ₂
	15–200	80–1070	100	50	25			
1,2,3-Trichloropropane	0.5–10	3–60	200	100	50	14		CS ₂
	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 ₂
	150–2000	1150–15 300	10	5	1			
Trifluoromonobromomethane ⁽⁷⁾	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 ₂
	15–200	84–1120	50	25	10			
Vinyl chloride ⁽⁷⁾	0.05–1	0.13–2.5	—	—	200		85 ± 5	CS ₂
	0.5–2	1.3–5.2	200	200	100			
Vinyl toluene	1–15	4.8–72	200	100	50	17	85 ± 10	CS ₂
	15–200	72–960	100	50	25			
Xylene	1–15	4.4–65	200	100	50		95 ± 5	CS ₂
	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 ₂ + 1% methanol | 8 Tetrahydrofuran 0.5 ml |
| 2 CS ₂ + 5% 2-propanol | 9 Hexane 0.5 ml |
| 3 CS ₂ + 1% 2-propanol | 10 CS ₂ + 5% isoamyl alcohol |
| 4 Isopropanol | 11 Formic acid |
| 5 CS ₂ + 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 9.3 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 gases and vapours

Gas chromatography

This technique detects substances qualitatively and quantitatively. The chromatogram retention time is compound-specific, and peak-height indicates the concentration of pollutant in the air. Detection systems include flame ionization, thermal conductivity and electron capture. Traditionally gas chromatography is a laboratory analysis but portable versions are now available for field work. Table 9.4 lists conditions for one such portable device.

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. The most commonly used portable gas detection system is based on the colour indicator tube. This system is mainly employed for grab sampling, with tubes to detect over 200 different gases (Table 9.5). It relies on a manually operated piston or bellows 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 with a specific pollutant or class of pollutant. The tube is generally calibrated so that the length of stain that develops can be read off directly in parts per million. Sample lines of several metres between pump and detector tube allow atmospheres to be sampled, e.g. inside vessels. A smaller number of special tubes are available for long-term monitoring and are used in conjunction with battery-powered pumps operating at a flow rate of 10–20 ml/s. Again the average concentration can be read off directly after a set period, e.g. 8 hours. Because of their simplicity, colour indicator tubes are widely used. However, their limitations must be appreciated; sources of inaccuracy are given in Table 9.6.

Portable or fixed multipoint colorimetric detectors are available which rely on paper tape impregnated with 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 readout of concentration. Such instruments are available for a range of chemicals including those in Table 9.7.

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. Table 9.8 lists some compounds detectable by one type of portable ir analyser.

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 9.9.

Table 9.4 Chromatographic column guide for Century organic vapour analyser

Compound	Relative response ⁽¹⁾ (%)	Column temperature ⁽²⁾ (°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

Table 9.4 Cont'd

Compound	Relative response ⁽¹⁾ (%)	Column temperature ⁽²⁾ (°C)	Column packing retention time (min:secs)		
			B-8	G-8	T-8
2-Chloro-1,1,2-trifluoroethyl difluoromethyl ether (Ethrane)	150	0	0:36	0:26	1:22
Cumene	100	40	0:13	0:12	0:19
		0	11:00	20:00	12:45
Cyclohexane	85	40	2:20	3:03	2:19
		0	0:36	1:25	0:19
Cyclohexanone	100	40	0:18	0:26	0:14
		0	18:00	12:45	—
<i>n</i> -Decane	75	40	3:00	2:00	—
		0	—	—	—
<i>o</i> -Dichlorobenzene	50	40	2:57	6:20	1:35
		0	—	—	—
Dichlorodifluoromethane (Freon 12)	15	40	8:06	10:00	11:20
		0	0:10	0:11	0:12
1,1 Dichloroethane	80	40	—	—	—
		0	0:17	0:37	0:45
1,2 Dichloroethane	80	40	0:08	0:17	0:18
		0	1:14	1:08	3:50
<i>trans</i> 1,2-Dichloroethylene	50	40	0:23	0:22	0:43
		0	0:16	0:35	0:31
Dichlorofluoromethane (Freon 21)	70	40	0:05	0:18	0:16
		0	0:16	0:15	0:23
Dichloromethane	100	40	—	—	—
		0	0:27	0:29	1:08
1,2-Dichloropropane	90	40	0:10	0:10	0:22
		0	0:41	1:49	2:56
1,3-Dichloropropane	80	40	0:18	0:29	0:36
		0	1:32	4:12	4:24
1,2-Dichloro 1,1,2,2,-tetrafluoroethane (Freon 114)	110	40	0:26	0:47	1:20
		0	0:12	0:12	0:14
Diethyl ether	50	40	—	—	—
		0	0:20	0:26	0:19
Diethyl ketone	80	40	0:05	0:05	0:05
		0	2:00	2:01	3:16
<i>p</i> -Dioxane	30	40	0:29	0:30	0:49
		0	3:15	2:09	6:40
Ethane	80	40	0:44	0:34	1:19
		0	0:15	0:15	0:15
Ethanethiol	30	40	—	—	—
		0	0:18	0:24	0:26
Ethanol	25	40	0:13	0:12	0:14
		0	0:59	0:31	0:26
Ethyl acetate	65	40	0:26	0:22	0:43
		0	0:48	1:00	2:20
Ethyl acrylate	40	40	0:20	0:20	0:31
		0	1:40	2:10	4:08
Ethyl benzene	100	40	0:30	0:30	0:50
		0	6:10	9:31	7:44
Ethyl butyrate	70	40	1:15	1:35	1:35
		0	4:34	6:22	8:00
		40	0:48	1:07	1:24

Table 9.4 Cont'd

Compound	Relative response ⁽¹⁾ (%)	Column temperature ⁽²⁾ (°C)	Column packing retention time (min:secs)		
			B-8	G-8	T-8
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
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

Table 9.4 Cont'd

Compound	Relative response ⁽¹⁾ (%)	Column temperature ⁽²⁾ (°C)	Column packing retention time (min:secs)		
			B-8	G-8	T-8
Pentanol	40	0	12:00	6:00	20:00
Propane	80	40	2:44	1:17	3:36
		0	0:05	0:11	0:05
<i>n</i> -Propanol	40	40	—	—	—
		0	2:50	1:00	6:30
2-Propanol	65	40	0:35	0:30	1:05
		0	1:13	0:30	3:43
<i>n</i> -Propyl acetate	75	40	0:25	0:20	0:38
		0	2:04	2:52	5:52
<i>n</i> -Propyl ether	65	40	0:30	0:38	0:51
		0	1:37	2:06	1:15
<i>n</i> -Propyl formate	50	40	0:43	0:29	0:18
		0	0:46	1:07	2:10
Pyridine	128	40	0:17	0:18	0:27
		0	8:00	4:15	—
Styrene	85	40	—	1:26	—
		0	20:00	25:00	28:00
1,1,1,2-Tetrachloroethane	100	40	2:06	2:26	2:39
		0	8:25	7:48	10:00
1,1,2,2-Tetrachloroethane	100	40	1:16	1:27	1:37
		0	32:00	14:00	50:00
Tetrachloroethylene	70	40	4:09	2:37	7:51
		0	3:00	5:45	2:10
Tetrahydrofuran	40	40	0:41	1:06	0:33
		0	1:05	1:05	1:45
Toluene	110	40	0:23	0:23	0:30
		0	2:30	4:05	4:30
1,1,1 Trichloroethane	105	40	0:38	0:47	0:53
		0	0:31	1:10	0:47
1,1,2 Trichloroethane	85	40	0:15	0:23	0:20
		0	5:13	3:43	15:00
Trichloroethylene	70	40	0:40	0:45	2:30
		0	1:17	2:02	1:25
Trichlorotrifluoroethane (Freon 113)	80	40	0:23	0:28	0:28
		0	0:15	0:30	0:16
Triethylamine	70	40	0:13	0:14	0:13
		0	—	2:49	—
Vinyl acetate	50	40	—	—	—
		0	0:34	0:43	1:55
Vinylidene chloride	40	40	0:15	0:17	0:30
		0	0:20	0:25	0:22
<i>m</i> -Xylene	111	40	0:13	0:14	0:14
		0	2:39	12:03	8:31
<i>o</i> -Xylene	116	40	0:39	1:43	1:17
		0	3:29	15:07	8:40
<i>p</i> -Xylene	116	40	0:48	1:58	1:45
		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

- (1) 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.
- (2) 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 9.5 Compounds for which colour detector tubes are available from one supplier

Dräger tubes for short-term measurements	
<i>Dräger tube</i>	<i>Range of measurement (20°C, 1013 mbar)</i>
Acetaldehyde 100/a	100–1000 ppm
Acetic acid 5/a	5–80 ppm
Acetone 100/b	100–12 000 ppm
Acrylonitrile 0.5/a	0.5–10 ppm
	1–20 ppm
Acrylonitrile 1/a	1–30 ppm
Alcohol 100/a	10–3000 ppm
Ammonia 2/a	2–30 ppm
Ammonia 5/a	5–70 ppm
	50–700 ppm
Ammonia 25/a	25–700 ppm
Ammonia 0.5%/a	0.5–10 vol.%
	0.05–1 vol.%
Aniline 0.5/a	0.5–10 ppm
Aniline 5/a	1–20 ppm
Arsenic trioxide 0.2/a	0.2 mg/m ³
Arsine 0.05/a	0.05–3 ppm
	1–60 ppm
Benzene 2/a	2–60 ppm
Benzene 0.5/a	0.5–10 ppm
Benzene 5/a	5–40 ppm
Benzene 5/b	5–50 ppm
Benzene 0.05	15–420 ppm
	(0.05–1.4 mg/l)
Carbon dioxide 0.01%/a	0.01–0.3 vol.%
Carbon dioxide 0.1%/a	0.1–1.2 vol.%
	0.5–6 vol.%
Carbon dioxide 0.5%/a	0.5–10 vol.%
Carbon dioxide 1%	1–20 vol.%
Carbon dioxide 5%/A	5–60 vol.%
Carbon disulphide 5/a	5–60 ppm
Carbon disulphide 0.04	13–288 ppm
	(0.04–0.9 mg/l)
Carbon disulphide 30/a	0.1–10 mg/l
	(32–3200 ppm)
Carbon monoxide 2/a	2–60 ppm
Carbon monoxide 5/c	5–150 ppm
	100–700 ppm
Carbon monoxide 8/a	8–150 ppm
(only for CO in H ₂)	

Table 9.5 Cont'd

Dräger tubes for short-term measurements	
<i>Dräger tube</i>	<i>Range of measurement (20°C, 1013 mbar)</i>
Carbon monoxide 10/b	10–300 ppm
Carbon monoxide 0.001%/a	100–3000 ppm 0.001–0.03 vol. % (10–300 ppm) 0.01–0.3 vol. % (100–3000 ppm)
Carbon monoxide 200/a	200–2500 ppm
Carbon monoxide 0.3%/a	0.3–7 vol. %
Carbon tetrachloride 1/a	1–15 ppm
Carbon tetrachloride 5/c	5–50 ppm
Chlorine 0.2/a	0.2–3 ppm 2–30 ppm
Chlorine 0.3/b	0.3–5 ppm
Chlorine 50/a	50–500 ppm
Chlorobenzene 5/a	5–200 ppm
Chloroform 2/a	2–10 ppm
Chloroformates 0.2/b	0.2–10 ppm
Chloroprene 5/a	5–60 ppm 7.5–90 ppm
Chromic acid 0.1/a	0.1–0.5 mg CrO ₃ /m ³
Cyanide 2/a	2–15 mg CN/m ³
Cyanogen chloride 0.25/a	0.25–5 ppm
Cyclohexane 100/a	100–1500 ppm
Diethyl ether 100/a	100–4000 ppm
Dimethyl formamide 10/b	10–40 ppm
Dimethyl sulphate 0.005/c	0.005–0.05 ppm
Dimethyl sulphide 1/a	1–15 ppm
Epichlorohydrin 5/b	5–50 ppm
Ethyl acetate 200/a	200–3000 ppm
Ethyl benzene 30/a	30–400 ppm up to 600 ppm
Ethyl glycol acetate 50/a	50–700 ppm
Ethylene 0.5/a	0.5–10 ppm
Ethylene oxide 1/a	1–15 ppm
Ethylene 50/a	50–2500 ppm
Ethylene oxide 25/a	25–500 ppm
Ethyl glycol acetate 50/a	50–700 ppm
Fluorine 0.1/a	0.1–2 ppm
Formaldehyde 0.2/a	0.5–5 ppm
Formaldehyde 0.002	2–40 ppm (0.002–0.05 mg/l)
Formic acid 1/a	1–15 ppm
Hologenated hydrocarbons 100/a	100–2600 ppm
n-Hexane 100/a	100–3000 ppm
Hydrazine 0.25/a	0.25–3 ppm
Hydrocarbon 0.1%/b	0.1–1.3 vol. %
Hydrocarbon 2	2–23 mg/l
Hydrocarbon test	500–2500 ppm
Hydrochloric acid 1/a	1–10 ppm 2–20 ppm
Hydrochloric acid 50/a	50–500 ppm 500–5000 ppm

Table 9.5 Cont'd

Dräger tubes for short-term measurements Dräger tube	Range of measurement (20°C, 1013 mbar)
Hydrocyanic acid 2/a	2–30 ppm 10–150 ppm
Hydrogen 0.2%/a	0.2–3 vol.%
Hydrogen fluoride 1.5/b	1.5–15 ppm
Hydrogen sulphide 0.5/a	0.5–15 ppm 2.5–75 ppm
Hydrogen sulphide 1/c	1–20 ppm 10–200 ppm
Hydrogen sulphide 2/a	2–20 ppm 20–200 ppm
Hydrogen sulphide 5/b	5–60 ppm 50–600 ppm
Hydrogen sulphide 100/a	100–2000 ppm
Hydrogen sulphide 0.2%/A	0.2–7 vol.%
Hydrogen sulphide + sulphur dioxide 0.2%/A	0.2–7 vol.% 0.02–0.7 vol.%
Mercaptan 0.5/a	0.5–5 ppm
Mercaptan 2/a	2–100 ppm
Mercury vapour 0.1/b	0.1–2 mg/m ³
Methanol 50/a	50–3000 ppm
Methyl acrylate 5/a	5–200 ppm
Methyl bromide 3/a	3–35 ppm 10–100 ppm
Methyl bromide 5/b	5–50 ppm
Methylene chloride 100/a	100–2000 ppm
Monostyrene 10/a	10–200 ppm
Monostyrene 10/b	10–250 ppm
Monostyrene 50/a	50–400 ppm
Natural gas test	Qualitative
Nickel tetracarbonyl 0.1/a	0.1–1 ppm
Nitric acid 1/a	1–15 ppm 5–50 ppm
Nitrogen dioxide 0.5/c	0.5–10 ppm 5–25 ppm
Nitrogen dioxide 2/c	2–50 ppm 5–100 ppm
Nitroglycol 0.25/a	0.25 ppm
Nitrous fumes 0.5/a	0.5–10 ppm
Nitrous fumes 2/a	2–50 ppm 5–100 ppm
Nitrous fumes 20/a	20–500 ppm
Nitrous fumes 100/c	100–1000 ppm 500–5000 ppm
Nitrous fumes 300/a	300–2000 ppm 1000–5000 ppm
Oil 10/a-P	2.5–10 mg/m ³
Oil mist 1/a	1–10 mg/m ³
Olefine 0.05%/a	1–55 mg/l
Organic arsenic compounds and arsine	0.3 mg/m ³
Oxygen 5/B	5–23 vol.%
Ozone 0.05/a	0.05–1.4 ppm 0.5–14 ppm

Table 9.5 Cont'd

Dräger tubes for long-term measurements

<i>Dräger tube</i>	<i>Range of measurement in absolute units (20°C, 1013 mbar)</i>
Ozone 10/a	10–300 ppm
<i>n</i> -Pentane 100/a	100–1500 ppm
Perchloroethylene 2/a	2–40 ppm
Perchloroethylene 10/b	10–500 ppm
Perchloroethylene 0.1/a	0.1–1 ppm
Petroleum hydrocarbons 100/a	100–2500 ppm (<i>n</i> -octane)
Phenol 1/b	1–20 ppm
Phosgene 0.02/a	0.02–1 ppm
	0.02–0.6 ppm
Phosgene 0.25/b	0.25–15 ppm
	1.25–75 ppm
Phosphine 0.01/a	0.1–1 ppm
	0.01–0.3 ppm
Phosphine 0.1/a	0.1–4 ppm
	1–40 ppm
Phosphine 25/a	200–10 000 ppm
	25–900 ppm
Phosphine 50/a	50–1000 ppm
	15–300 ppm
	150–3000 ppm
Phosphoric acid esters 0.05/a	0.05 ppm (dimethyldichloro- vinylphosphate)
Pyridine 5/A	5 ppm
Sulphur dioxide 0.1/a	0.1–3 ppm
Sulphur dioxide 0.5/a	0.5–5 ppm
	1–25 ppm
Sulphur dioxide 1/a	1–25 ppm
Sulphur dioxide 20/a	20–200 ppm
	200–2000 ppm
Sulphur dioxide 50/b	50–500 ppm
Sulphuric acid 1/a	1–5 mg/m ³
Tetrahydrothiophene 1/b	1–10 ppm
Toluene 5/a	5–400 ppm
Toluene 25/a	0.1–7 mg/l (25–1860 ppm)
Toluene diisocyanate 0.02/A	0.02–0.2 ppm
Toluidine 1/a	1–30 ppm
Trichloroethane 50/d	50–600 ppm
Trichloroethylene 2/a	2–50 ppm
	20–200 ppm
Trichloroethylene 10/a	10–500 ppm
Triethylamine 5/a	5–60 ppm
Vinyl chloride 0.5/a	0.5–3 ppm
	0.25–1.5 ppm
	1–6 ppm
Vinyl chloride 1/a	1–10 ppm
	5–50 ppm
Vinyl chloride 100/a	100–3000 ppm
Water vapour 0.1/a	0.1–40 mg/l
Water vapour 1/a	1–18 mg/l
Xylene 10/a	10–400 ppm

Table 9.5 Cont'd

Dräger tubes for long-term measurements <i>Dräger tube</i>	<i>Range of measurement in absolute units (20°C, 1013 mbar)</i>	<i>Range of measurement for maximum period of use</i>
Acetic acid 5/a	5–40 ppm	1.25–10 ppm (4 hr)
Acetone 500/a-L	500–10 000 ppm	63–1250 ppm (8 hr)
Ammonia 10/a-L	10–100 ppm	2.5–25 ppm (4 hr)
Benzene 20/a-L	20–200 ppm	10–100 ppm (2 hr)
Carbon dioxide 1000/a-L	1000–6000 ppm	250–1500 ppm (4 hr)
Carbon disulphide 10/a-L	10–100 ppm	1.3–13 ppm (8 hr)
Carbon monoxide 10/a-L	10–100 ppm	2.5–25 ppm (4 hr)
Carbon monoxide 50/a-L	50–500 ppm	6.3–63 ppm (8 hr)
Chlorine 1/a-L	1–20 ppm	0.13–2.5 ppm (8 hr)
Chloroprene 5/a-L	5–100 ppm	1.3–25 ppm (4 hr)
Ethanol 500/a-L	500–8000 ppm	63–1000 ppm (8 hr)
Hydrocarbon 100/a-L	100–3000 ppm	25–750 ppm (4 hr)
Hydrochloric acid 10/a-L	10–50 ppm	1.3–6.3 ppm (8 hr)
Hydrocyanic acid 10/a-L	10–120 ppm	1.3–15 ppm (8 hr)
Hydrogen fluoride 2/a-L	2–30 ppm	0.25–3.8 ppm (8 hr)
Hydrogen sulphide 5/a-L	5–60 ppm	0.63–7.5 ppm (8 hr)
Methylene chloride 50/a-L	50–800 ppm	13–200 ppm (4 hr)
Nitrogen dioxide 10/a-L	10–100 ppm	1.3–13 ppm (8 hr)
Oxides of nitrogen 5/a-L (NO + NO ₂)	5–50 ppm	1.3–13 ppm (4 hr)
Oxides of nitrogen 50/a-L (NO + NO ₂)	50–350 ppm	2–175 ppm (4 hr)
Perchloroethylene 50/a-L	50–300 ppm	13–75 ppm (4 hr)
Sulphur dioxide 5/a-L	2–20 ppm	0.5–5 ppm (8 hr)
Sulphur dioxide 2/a-L	5–50 ppm	1.3–13 ppm (4 hr)
Toluene 200/a-L	200–4000 ppm	25–500 ppm (8 hr)
Trichloroethylene 10/a-L	10–200 ppm	2.5–50 ppm (4 hr)
Vinyl chloride 10/a-L	10–50 ppm	1–5 ppm (10 hr)

Table 9.6 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 pumphousing (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 these 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.
Ill-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 9.7 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 9.8 Compounds detectable by portable infrared analysis (MIRAN 1A)

<i>Compound</i>	<i>Analytical Wavelength (μm)⁽¹⁾</i>	<i>Path length (m)⁽²⁾</i>	<i>Absorbance⁽³⁾</i>	<i>Minimum Detectable Concentration (ppm)⁽⁴⁾</i> (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, see 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, see 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, see Carbaryl				
Benzene	14.87	20.25	0.08	0.3
<i>p</i> -Benzoquinone, see Quinone				
Benzyl Chloride	7.9	20.25	0.0012	0.4
Bisphenol A, see 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, see 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

Table 9.8 Cont'd

Compound	Analytical Wavelength (µm) ⁽¹⁾	Path length (m) ⁽²⁾	Absorbance ⁽³⁾	Minimum Detectable Concentration (ppm) ⁽⁴⁾ (20 metre cell)
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 ⁽⁵⁾				
Chlorinated camphene ⁽⁵⁾				
Chlorobenzene (monochlorobenzene)	9.2	20.25	0.26	0.2
Chlorobromomethane	8.1	9.75	0.29	0.2
2-Chloro-1,3-butadiene, see Chloroprene				
Chlorodifluoromethane (Freon 22)	9.0	5.25	0.17	0.02
1-Chloro,2,3-Epoxypropane, see Epichlorohydrin				
2-Chloroethanol, see Ethylene chlorohydrin				
Chloroethylene, see 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
Demeton V				
Deuterium oxide	3.68	20.25	0.067	1.0
DDVP, see Dichlorvos				
Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)	8.5	20.25	0.335	0.08
1,2-Diaminoethane, see Ethylenediamine				
Diborane	3.9	20.25	0.0005	0.1
Dibromochloropropane	8.27	20.25	0.19	0.2

Table 9.8 Cont'd

Compound	Analytical Wavelength (μm) ⁽¹⁾	Path length (m) ⁽²⁾	Absorbance ⁽³⁾	Minimum Detectable Concentration (ppm) ⁽⁴⁾ (20 metre cell)
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
Dichloroethyl ether	8.85	20.25	0.13	0.06
Dichloromethane, see 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, see 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, see 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 ⁽⁶⁾				
Dihydroxybenzene, see 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, see Methylal				
<i>N,N</i> -Dimethylacetamide	9.9	20.25	0.02	0.3
Dimethylamine	8.7	20.25	0.02	0.5
Dimethylaminobenzene, see Xylidene				
Dimethylaniline (N, N dimethyl aniline)	8.6	20.25	0.015	0.2
Dimethylbenzene, see Xylene				
Dimethylformamide	9.2	20.25	0.063	0.1
2,6-Dimethylheptanone, see 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, see 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, see Propylene oxide				
2,3-Epoxy-1-propanol, see Glycidol				
Ethanethiol, see 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

Table 9.8 Cont'd

<i>Compound</i>	<i>Analytical Wavelength (μm)⁽¹⁾</i>	<i>Path length (m)⁽²⁾</i>	<i>Absorbance⁽³⁾</i>	<i>Minimum Detectable Concentration (ppm)⁽⁴⁾</i> (20 metre cell)
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, 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 ^(R) , 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

Table 9.8 Cont'd

Compound	Analytical Wavelength (μm) ⁽¹⁾	Path length (m) ⁽²⁾	Absorbance ⁽³⁾	Minimum Detectable Concentration (ppm) ⁽⁴⁾ (20 metre cell)
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
Hydrogen cyanide	3.04	20.25	0.0083	0.4
Hydroquinone ⁽⁵⁾				
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
Isopentane	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 ⁽⁵⁾				
Methylene chloride	13.4	0.75	0.25	0.2
Methyl ethyl ketone (MEK), see 2-Butanone				
<i>N</i> -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

Table 9.8 Cont'd

<i>Compound</i>	<i>Analytical Wavelength (μm)⁽¹⁾</i>	<i>Path length (m)⁽²⁾</i>	<i>Absorbance⁽³⁾</i>	<i>Minimum Detectable Concentration (ppm)⁽⁴⁾</i> (20 metre cell)
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				
α-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 ₂)	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				
Phenyhydrazine	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 ⁽⁵⁾				
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				

Table 9.8 Cont'd

<i>Compound</i>	<i>Analytical Wavelength (μm)⁽¹⁾</i>	<i>Path length (m)⁽²⁾</i>	<i>Absorbance⁽³⁾</i>	<i>Minimum Detectable Concentration (ppm)⁽⁴⁾ (20 metre cell)</i>
Pyridine	14.2	20.25	0.05	0.2
Quinone ⁽⁵⁾				
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 ⁽⁶⁾				
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 ⁽⁵⁾				
Toluene	13.7	6.75	0.38	0.5
<i>o</i> -Toluidine	13.5	20.25	0.029	0.5
Toxaphene, see Chlorinated camphene				
Tributyl phosphate				
1,1,1-Trichloroethane, see Methyl chloroform	10.7	20.25	0.020	0.3
1,1,2-Trichloroethane	11.8	5.25	0.27	0.1
Trichloroethylene				
Trichloromethane, see Chloroform	12.4	20.25	0.16	0.4
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
Triethylamine				
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 CO₂. 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 9.9 Selected examples of compound specific instruments

<i>Compound</i>	<i>Detection system</i>
Carbon monoxide	Polarography
Chlorine	Ultraviolet spectroscopy
Hydrogen chloride	Polarography
Hydrogen fluoride	Polarography Colorimetry
Oxides of nitrogen	Chemiluminescence Coulometry
Oxygen	Polarography Paramagnetic susceptibility Fluorescence
Ozone	Ultraviolet spectroscopy Chemiluminescence Coulometry
Phosgene	Ultraviolet spectroscopy
Sulphur compounds	Flame photometry Coulometry

Table 9.10 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

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. Points to consider are listed in Table 9.10.

Semiconductors resembling Pellistors are also used, 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.

Toxic particulates

Many dust 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 provides a useful 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.

The air in the general working 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. Techniques for separating dust or aerosol particles of respirable dimensions for 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 ≤ 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 9.11. In filtration, e.g. for gravimetric analysis, selection of filter material requires careful consideration in terms of strength, collection efficiency, compatibility with pump, water uptake, etc. Humidity-controlled balance rooms, microbalances and careful handling techniques are required.

Official methods

Regulatory and advisory bodies publish methods for ambient air analysis such as those from HSE, the British Standards Institution and NIOSH listed in Table 9.12. Table 9.13 provides additional data on analytical techniques for a selection of substances.

Table 9.11 Particulates monitoring – principles of apparatus

<i>Principle</i>	<i>Examples</i>	<i>Collection</i>	<i>Sampling rate (l/min)</i>	<i>Collection efficiency (%)</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.
Impactor	1. Konimeter	Impaction on gel-coated disc	1–37 (depending on type)	60–100	Built-in microscope 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	Poor for large particles. Collection efficiency increases as particle size decreases.
Filtration	1. Fibrous filter		1–50	85–100 Depends on particle size values stated for those usually encountered	Gravimetric or chemical	Fibrous filter good for gravimetric analysis (fast and relatively easy). Membrane filter good for microscopy identification of particles and counting where required.
	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, microscopic or chemical	The only instrument for carrying out personal respirable dust sampling.
Beta attenuation		Impaction on disc or filtration			Attenuation of beta radiation Direct reading	Provides short- or long-term TWA (e.g. up to 8 hr, depending on model) of dust or fume mass concentration.
Photometry	1. Number concentration, e.g. Royco				Light scattered on to a photomultiplier Direct reading	Gives automatic particle sizing but accuracy only guaranteed if calibrated for particulate of interest.
	2. Mass concentration, e.g. Simslin				Light scattered on to a photomultiplier Direct reading	Very versatile – only accurate continuous long-term mass monitoring instrument; sample may also be collected on a filter.
Piezoelectric		Electrostatic frequency of crystal. Direct reading			Change in resonant frequency	

Table 9.12 Methods of ambient air analysis published in the UK by the Health and Safety Executive and by BSI, and in the USA by NIOSH

HSE methods for the determination of hazardous substances (MDHS)

MDHS 1 <i>Acrylonitrile in air</i> Laboratory method using charcoal adsorption tubes and gas chromatography	MDHS 19 <i>Formaldehyde in air</i> Colorimetric field method using 4,5-dihydroxy-2,7-naphthalenedisulphonic acid
MDHS 2 <i>Acrylonitrile in air</i> Laboratory method using porous polymer adsorption tubes, and thermal desorption with gas chromatographic analysis	MDHS 20 <i>Styrene in air</i> Laboratory method using charcoal adsorbent tubes, solvent desorption and gas chromatography
MDHS 3 <i>Generation of test atmospheres of organic vapours by the syringe injection technique</i> Portable apparatus for laboratory and field use	MDHS 21 <i>Glycol ether and glycol ether vapours in air</i> Laboratory method using charcoal adsorbent tubes, solvent desorption and gas chromatography
MDHS 4 <i>Generation of test atmospheres of organic vapours by the permeation tube method</i> Apparatus for laboratory use	MDHS 22 <i>Benzene in air</i> Laboratory method using porous polymer adsorbent tubes, thermal desorption and gas chromatography
MDHS 5 <i>On-site validation of sampling methods</i>	MDHS 23 <i>Glycol ether and glycol ether vapours in air</i> Laboratory method using Tenax adsorbent tubes, thermal desorption and gas chromatography
MDHS 6 <i>Lead and inorganic compounds of lead in air</i> Laboratory method using atomic absorption spectrometry	MDHS 24 <i>Vinyl chloride in air</i> Laboratory method using charcoal adsorbent tubes, solvent desorption and gas chromatography
MDHS 7 <i>Lead and inorganic compounds of lead in air</i> Laboratory method using X-ray fluorescence spectrometry	MDHS 25 <i>Organic isocyanates in air</i> Laboratory method using 1-(2-methoxyphenyl) piperazine solution and high-performance liquid chromatography
MDHS 8 <i>Lead and inorganic compounds of lead in air</i> Colorimetric field method using sym-diphenylthio-carbazone (dithizone)	MDHS 26 <i>Ethylene oxide in air</i> Laboratory method using charcoal adsorbent tubes, solvent desorption and gas chromatography
MDHS 9 <i>Tetra alkyl lead compounds in air</i> Personal monitoring method	MDHS 27 <i>Protocol for assessing the performance of a diffusive sampler</i>
MDHS 10 <i>Cadmium and inorganic compounds of cadmium in air</i> Laboratory method using atomic absorption spectrometry	MDHS 28 <i>Chlorinated hydrocarbon solvent vapours in air</i> Laboratory methods using charcoal adsorbent tubes, solvent desorption and gas chromatography
MDHS 11 <i>Cadmium and inorganic compounds of cadmium in air</i> Laboratory method using X-ray fluorescence spectrometry	MDHS 29 <i>Beryllium and inorganic compounds of beryllium in air</i> Laboratory method using atomic absorption spectrometry
MDHS 12 <i>Chromium and inorganic compounds of chromium in air</i> Laboratory method using atomic absorption spectrometry	MDHS 30 <i>Cobalt and inorganic compounds of cobalt in air</i> Laboratory method using atomic absorption spectrometry
MDHS 13 <i>Chromium and inorganic compounds of chromium in air</i> Laboratory method using X-ray fluorescence spectrometry	MDHS 31 <i>Styrene in air</i> Laboratory method using porous polymer adsorbent tubes, thermal desorption and gas chromatography
MDHS 14 <i>General method for the gravimetric determination of respirable and total dust</i>	MDHS 32 <i>Diocetyl phthalates in air</i> Laboratory method using Tenax adsorbent tubes, solvent desorption and gas chromatography
MDHS 15 <i>Carbon disulphide</i>	MDHS 33 <i>Adsorbent tube standards</i> Preparation by the syringe loading technique
MDHS 16 <i>Mercury vapour in air</i> Laboratory method using hopcalite adsorbent tubes, and acid dissolution with cold vapour atomic absorption spectrometric analysis	MDHS 34 <i>Arsine in air</i> Colorimetric field method using silver diethyl-dithiocarbamate in the presence of excess silver nitrate
MDHS 17 <i>Benzene in air</i> Laboratory method using charcoal adsorbent tubes, solvent desorption and gas chromatography	MDHS 35 <i>Hydrogen fluoride and inorganic fluorides in air</i> Laboratory method using an ion-selective electrode
MDHS 18 <i>Tetra alkyl lead compounds in air</i> Continuous on-site monitoring method using PAC Check atomic absorption spectrometry	

Table 9.12 cont'd

A selection of relevant British Standards

- BS 893 Methods for the measurement of the concentration of particulate material in ducts carrying gases.
- BS 1747 Methods for the measurement of air pollution.
- Pt 1 – Deposit gauges.
 - Pt 2 – Determination of concentration of suspended matter.
 - Pt 3 – Determination of sulphur dioxide.
 - Pt 4 – The lead dioxide method.
 - Pt 5 – Directional dust gauges.
 - Pt 6 – Sampling equipment used for the determination of gaseous sulphur compounds in ambient air.
 - Pt 7 – Determination of mass concentration of sulphur dioxide in ambient air. Thorin spectrophotometric method.
- BS 1756 Methods for the sampling and analysis of flue gases.
- Pt 1 – Methods of sampling.
 - Pt 2 – Analysis by the Orsat apparatus.
 - Pt 3 – Analysis by the Haldane apparatus.
 - Pt 4 – Miscellaneous analysis.
 - Pt 5 – Semi-routine analysis.
- BS 3405 Method for the measurement of particulate emission including grit and dust (simplified method).
- BS 4947 Specification for test gases for gas appliances.
- BS 5243 General principles for sampling airborne radioactive materials.
- BS 5343 Specification for gas-detection tubes.
- BS 6020 Instruments for the detection of combustible gases.
- Pt 1 – Specification for general requirements and test methods.
 - Pt 2 – Specification for safety and performance requirements for Group I instruments reading up to 5% methane in air.
 - Pt 3 – Specification for safety and performance requirements for Group I instruments reading up to 100% methane.
 - Pt 4 – Specification for performance requirements for Group II instruments reading up to 100% lower explosive limit.
 - Pt 5 – Specification for performance requirements for Group II instruments reading up to 100% gas.
- Drafts for Development
- (DD 54) – Methods for the sampling and analysis of fume from welding and allied processes.
- Pt 1 – Particulate matter.
 - Pt 2 – Gases.

Compounds for which there are analytical methods recommended by NIOSH

Acetaldehyde	2-Aminopyridine
Acetic acid	Ammonia
Acetic anhydride	Ammonium sulphamate
Acetone	Amorphous silica
Acetone cyanohydrin	<i>n</i> -Amyl acetate
Acetonitrile (methyl cyanide)	<i>sec</i> -Amyl acetate (α -methylbutyl acetate)
Acetylene dichloride (1,2-dichloroethylene)	Aniline
Acetylene tetrabromide (tetrabromoethane)	Anisidine
Acid mists	Anthanthrene
Acrolein	Anthracene
Acrylonitrile	Antimony
ALAD (δ -aminolevulinic acid dehydratase)	ANTU (δ -naphthyl thiourea)
Aldrin	Arsenic
Allyl alcohol	Arsine
Allyl chloride	Asbestos
Allyl glycidyl ether	Azelaic acid
Aluminium	Aziridine
Amines, aliphatic	Azo dyes
Amines, aromatic	
4-Aminobiphenyl	Barium
Aminoethanol compounds	Benz(c)acridine
bis (2-Aminoethyl) amine (diethylenetriamine)	Benz(a)anthracene
<i>p</i> -Aminophenylarsonic acid	Benz(a,h)anthracene
	Benz(a)anthrone

Benzene	1-Chloro-1-nitropropane
Benzene, chlorinated	Chloroacetaldehyde
Benzene-solubles	α -Chloroacetophenone
Benzidine	Chlorobenzene (monochlorobenzene)
Benzidine-based dyes	<i>o</i> -Chlorobenzylidene malononitrile
Benzo Azurine G	Chlorobromomethane
Benzo(b)fluoranthene	Chlorodiphenyl (42% chlorine)
Benzo(j)fluoranthene	Chlorodiphenyl (54% chlorine)
Benzo(k)fluoranthene	2-Chloroethanol (ethylene chlorohydrin)
Benzo(g,h,i)perylene	Chloroform
Benzopurpurine 4B	Chloroform methyl ether
Benzo(a)pyrene	<i>p</i> -Chlorophenol
Benzo(c)pyrene	Chromic acid
Benzoyl peroxide	Chromium
Benzyl chloride	Chromium fume
Beryllium	Chrysene
Bibenzyl	Chrysotile
Biphenyl (diphenyl)	Coal-tar naphtha (naphtha, coal tar)
Biphenyl-phenyl ether mixture (phenyl ether-biphenyl vapour mixture)	Coal-tar pitch volatiles
Bis(chloromethyl)ether	Cobalt
2,2-Bis[4-(2,3-epoxypropoxy)phenyl] propane	Cobalt, metal, dust, and fume
Bismuth	Congo red
Bisphenol A	Copper
2,2-Bis(<i>p</i> -chlorophenyl) 1,1,1-trichloroethane (DDT)	Copper dust and mists
Boron carbide	Copper fume
Boron oxide	Crag herbicide I
Bromoform	Cresol, all isomers
Butadiene (1,3-butadiene)	Cristobalite
1-Butanethiol (<i>n</i> -butyl mercaptan)	Crotonaldehyde
2-Butanone (methyl ethyl ketone or MEK)	Cumene
2-Butoxy ethanol (butyl cellosolve)	Cyanide
sec-Butyl acetate	Cyclohexane
tert-Butyl acetate	Cyclohexanol
Butyl acetate (<i>n</i> -Butyl acetate)	Cyclohexanone
sec-Butyl alcohol	Cyclohexene
tert-Butyl alcohol	Cyclohexylamine
Butyl alcohol (<i>n</i> -butyl alcohol)	Cyclopentadiene
Butyl cellosolve (2-butoxy ethanol)	
<i>n</i> -Butyl glycidyl ether	DBPC
<i>n</i> -Butyl mercaptan	2,4 D
<i>n</i> -Butylamine	DDT (2,2-Bis(<i>p</i> -chlorophenyl)-1,1,1-trichloroethane)
<i>p</i> -tert-Butyltoluene	DDVP
	Demeton
Cadmium	Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)
Calcium	1,2-Diaminoethane (ethylene diamine)
Calcium arsenate	<i>o</i> -Dianisidine-based dyes
Calcium oxide	Diazomethane
Camphor	Diazonium salts
Carbaryl® (Sevin)	Diborane
Carbon black	1,2-Dibromoethane (ethylene dibromide)
Carbon dioxide	2-Dibutylaminoethanol (aminoethanol compounds)
Carbon disulphide	Dibutyl phosphate
Carbon monoxide	Dibutylphthalate
Carbon tetrachloride	1,1-Dichloro-1-nitroethane
Carbonyl chloride (phosgene)	<i>o</i> -Dichlorobenzene
Chlordane	<i>p</i> -Dichlorobenzene
Chloride	3,3'-Dichlorobenzidine
Chlorinated camphene (toxaphene)	Dichlorodifluoromethane (Refrigerant 12)
Chlorinated diphenyl oxide	1,1-Dichloroethane (ethylidene chloride)
Chlorine	1,2-Dichloroethane (ethylene dichloride)
2-Chloro-1,3-butadiene (chloroprene)	Dichloroethyl ether
1-Chloro-2,3-epoxypropane (epichlorohydrin)	1,2-Dichloroethylene (acetylene dichloride)
	Dichloromethane (methylene chloride)

Table 9.12 cont'd

Dichloromonofluoromethane (Refrigerant 21)	2-Ethoxyethylacetate
2,4-Dichlorophenoxyacetic acid and salts	Ethyl acrylate
1,2-Dichloropropane	Ethyl alcohol (ethanol)
Dichlorotetrafluoroethane (Refrigerant 114)	Ethyl benzene
Dichloro-5-triazine-2,4,6-trione, sodium salt	Ethyl bromide
Dichlorovos	Ethyl butyl ketone (3-heptanone)
Dieldrin	Ethyl chloride
2-Diethylaminoethanol	Ethyl ether
Diethylamine	Ethyl formate
Diethylcarbamoyl chloride	Ethyl sec-amyl ketone (5-methyl-3-heptanone)
Diethylene dioxide (dioxane)	Ethyl silicate
Diethylenetriamine	O-Ethyl-O- <i>p</i> -nitrophenyl phenyl-phosphonothiolate phosphonate (EPN)
Difluorodibromomethane	Ethylamine
Difluorodichloromethane	Ethylene chloride (ethylene dichloride)
Diglycidyl ether of Bisphenol A	Ethylene chlorohydrin (2-chloroethanol)
Diisobutyl ketone (2,6-dimethyl-4-heptanone)	Ethylenediamine
Diisopropylamine	Ethylene dibromide (1,2-dibromoethane)
Dimethoxymethane (methylal)	Ethylene dichloride (1,2-dichloroethane)
Dimethyl acetamide	Ethylene glycol
Dimethyl benzene (xylene)	Ethylene glycol dinitrate
1,3-Dimethyl butyl acetate (sec-hexyl acetate)	Ethylene oxide
Dimethyl formamide	Ethylene thiourea
2,6-Dimethyl-4-heptanone (diisobutyl ketone)	Ethylenimine
Dimethyl sulphate	di-2-Ethylhexylphthalate (di-sec-octyl phthalate)
N,N-Dimethyl- <i>p</i> -toluidine	Ethylidene chloride (1,1-dichloroethane)
Dimethylamine	N-Ethylmorpholine
4-Dimethylaminoazobenzene	
2,4-Dimethylaminobenzene (xylydine)	Fluoranthene
N,N-Dimethylaniline	Fluoride
Dimethylarsenic acid	Fluoroacetate, sodium
1,1-Dimethylhydrazine	Fluorotrichloromethane (Refrigerant 11)
Dimethylnitrosamine	Formaldehyde
bis (Dimethylthiocarbamoyl) disulphide	Formic acid
Dinitrobenzene (all isomers)	Furfural
Dinitro <i>o</i> -cresol	Furfuryl alcohol
Dinitrotoluene	
Dioxane	Galena
Diphenyl	Gallium
4,4'-Methylenebisphenyl isocyanate (MDI)	Glycidol (2,3-epoxy-1-propanol)
Dipropylene glycol methyl ether	
Direct Black 38	Hafnium
Direct Blue 6	Heptachlor
Direct Blue 8	Heptane
Direct Brown 95	3-Heptanone (ethyl butyl ketone)
Direct Red 2	2-Heptanone (methyl (<i>n</i> -amyl) ketone)
Direct Red 28	Hexachlorobutadiene
2,6-Di- <i>tert</i> -butyl- <i>p</i> -cresol	Hexachlorocyclopentadiene
Dowtherm A (phenyl etherbiphenyl vapour mixture)	Hexachloroethane
	Hexachloronaphthalene
Endrin	Hexamethylenetetramine
Epichlorohydrin (1-chloro-2,3-epoxypropane)	Hexane
EPN (O-ethyl-O- <i>p</i> -nitrophenyl phenyl-phosphonothiolate)	Hexavalent chromium
2,3-Epoxy-1-propanol (glycidol)	2-Hexanone (methyl butyl ketone or MBK)
1,2-Epoxypropane (propylene oxide)	Hexone (methyl isobutyl ketone or MIBK)
2,2-bis[4-(2,3-Epoxypropoxy) phenyl] propane	sec-Hexyl acetate (1,3-dimethyl butyl acetate)
Ethanol (ethyl alcohol)	Hippuric acid
Ethanolamine (aminoethanol compounds)	Hydrazine
Ether	Hydrogen bromide
2-Ethoxyethanol	Hydrogen chloride

Hydrogen cyanide
 Hydrogen fluoride
 Hydrogen sulphide
 Hydroquinone
 4-Hydroxy-4-methyl-2-pentanone (diacetone alcohol)

2-Imidazolidinethione (ethylene thiourea)

Indium

Iron

Iron oxide fume

Isoamyl acetate

Isoamyl alcohol

Isobutyl acetate

Isobutyl alcohol

Isophorone

Isopropanol (isopropyl alcohol)

Isopropyl acetate

Isopropyl alcohol (isopropanol)

Isopropyl benzene (cumene)

Isopropyl glycidyl ether

Isopropylamine

Isopropylether

4,4'-Isopropylidenediphenol

Kepone

Ketene

Lead

Lead sulphide

Lindane

Liquefied petroleum gas (LPG)

Lithium

LPG (liquefied petroleum gas)

MAPP (methyl acetylene/propadiene)

Magnesium

Magnesium oxide fume

Malathion

Maleic anhydride

Manganese

Manganese fume

MBK (2-hexanone)

MDI (4,4'-methylenebisphenyl isocyanate)

MEK (2-butanone)

Mercury

Mesityl oxide

Methanol (methyl alcohol)

2-Methoxyethanol (methyl cellosolve)

Methoxychlor

Methyl(*n*-amyl)ketone (2-heptanone)

5-Methyl-3-heptanone

Methyl acetate

Methyl acetylene

Methyl acetylene propadiene mixture

Methyl acrylate

Methyl alcohol (methanol)

Methyl bromide

α -Methyl butyl acetate (sec-amyl acetate)

Methyl butyl ketone (2-hexanone)

Methyl cellosolve (2-methoxyethanol)

Methyl cellosolve acetate

Methyl chloride

Methyl chloroform (1,1,1-trichloroethane)

Methyl cyanide (acetonitrile)

Methyl ethyl ketone (2-butanone)

Methyl ethyl ketone peroxide

Methyl formate

Methyl iodide

Methyl isoamyl acetate

Methyl isobutyl carbinol

Methyl isobutyl ketone (hexone)

Methyl methacrylate

α -Methyl styrene

Methylal (dimethoxymethane)

Methylamine

Methylcyclohexane

Methylcyclohexanol

Methylcyclohexanone

4,4'-Methylenebis (2-chloroaniline)

4,4'-Methylenebisphenyl isocyanate (MDI)

Methylene chloride (dichloromethane)

Methylhydrazine

Mevinphos[®]

MIBK (hexone)

MOCA

Molybdenum

Molybdenum insoluble compounds

Molybdenum soluble compounds

Monochloroacetic acid

Monochlorobenzene (chlorobenzene)

Monomethyl aniline

Monomethyl hydrazine

Monomethylarsonic acid

Morpholine

Naphtha, coal tar (coal-tar naphtha)

Naphthalene

Naphthylamines

α -Naphthyl thiourea

Nickel

Nickel carbonyl

Nickel fume

Nicotine

Nitric acid

Nitric oxide

p-Nitroaniline

Nitrobenzene

4-Nitrobiphenyl

p-Nitrochlorobenzene

Nitroethane

2-Nitropropane

Nitrogen dioxide

Nitroglycerin

Nitroglycol

Nitromethane

N-Nitrosodimethylamine

Nitrotoluene

Octachloronaphthalene

Octane

di-sec-octyl phthalate (di-2-ethylhexylphthalate)

Oil mist

Organic solvents

Organo(alkyl)mercury

Organoarsenicals

Ozone

Table 9.12 cont'd

Palladium	Rhodium, metal fume and dust
Paraquat	Rhodium, soluble salts
Parathion	Ronnel
PCBs	Rotenone
Pentachlorobenzene	Rubidium
Pentachloroethane	Selenium
Pentachloronaphthalene	Sevin (carbaryl)
Pentachlorophenol	Silica, amorphous
Pentane	Silica, crystalline
2-Pentanone	Silicon
Perchloroethylene (tetrachloroethylene)	Silver
Perylene	Silver, metal and soluble compounds
Petroleum distillates (petroleum naphtha)	Sodium
Petroleum naphtha (petroleum distillates)	Sodium dichloroisocyanate dihydrate
Phenacetylchloride	Sodium fluoroacetate
Phenanthrene	Sodium-2,4-dichlorophenoxyethyl sulphate
Phenol	Sodium hydroxide
Phenyl ether	Stibine
Phenyl ether-biphenyl vapor mixture (Dowtherm A)	Stoddard solvent
Phenyl ethylene (styrene)	Strontium
Phenyl glycidyl ether	Strychnine
Phenylhydrazine	Styrene (vinyl benzene)
Phenyloxirane	Styrene oxide
Phosdrin	Sulphate
Phosgene (carbonyl chloride)	Sulphite
Phosphate	Sulphur dioxide
Phosphine	Sulphur hexafluoride
Phosphoric acid	Sulphuric acid
Phosphorus (white, yellow)	Sulphuryl fluoride
Phosphorus pentachloride	Systox
Phosphorus trichloride	2,4,5-T
Phthalic anhydride	TDI (Toluene 2,4-diisocyanate)
Picric acid	Tantalum
Platinum, soluble salts	Tellurium
PNAs	Tellurium hexafluoride
Polychlorinated biphenyls (PCBs)	TEPP
Polymethylsiloxane	Terphenyl
Polynuclear aromatic hydrocarbons (PNAs)	Tetrabromoethane (acetylene tetrabromide)
Potassium	1,1,1,2-Tetrachloro-2,2-difluoroethane
Propane	1,1,2,2-Tetrachloro-1,2-difluoroethane (Refrigerant 112)
Propanol (Propyl alcohol)	1,2,4,5-Tetrachlorobenzene
<i>n</i> -Propyl acetate	1,1,2,2-Tetrachloroethane
Propyl alcohol (propanol)	Tetrachloroethylene (perchloroethylene)
<i>n</i> -Propyl nitrate	Tetrachloromethane (carbon tetrachloride)
Propylene dichloride	Tetrachloronaphthalene
Propylene oxide (1,2-epoxypropane)	Tetraethyl lead
Propyne	Tetraethyl pyrophosphate
Pyrene	Tetrahydrofuran
Pyrethrum	Tetramethyl lead (as Pb)
Pyridine	Tetramethyl succinonitrile
Quartz (silica, crystalline)	Tetramethyl thiourea
Quinone	Tetramethyl thiuram disulphide (thiram)
Refrigerant 11 (fluorotrichloromethane)	Tetranitromethane
Refrigerant 113 (1,1,2-trichloro-1,2,2-fluoroethane)	Tetryl (2,4,6-Trinitrophenylmethyl-nitramine)
Refrigerant 114 (dichlorotetrafluoromethane)	Thallium
Refrigerant 12 (dichlorodifluoromethane)	Thiopene
Refrigerant 21 (dichloromonofluoromethane)	Thiram (tetramethyl thiuram disulphide)
Rhodium	

Tin	2,4,6-Trinitrophenylmethylnitramine (Tetryl)
Tin, organic compounds	Triorthocresyl phosphate
Tissue preparation	Triphenyl phosphate
Titanium	Tungsten
Titanium diboride	Turpentine
Titanium dioxide	
o-Tolidine based dyes	Vanadium
Toluene	Vanadium, V ₂ O ₅ fume
Toluene-2,4-diisocyanate (TDI)	Vinyl acetate
o-Toluidine	Vinyl benzene (styrene)
Toxaphene (chlorinated camphene)	Vinyl bromide
Tributyl phosphate	Vinyl chloride
1,1,2-Trichloro-1,2,2-trifluoroethane (Refrigerant 113)	Vinyl toluene
1,2,4-Trichlorobenzene	Vinylidene chloride
1,1,1-Trichloroethane (Methyl chloroform)	
1,1,2-Trichloroethane	Warfarin
Trichloroethylene	
Trichloroisocyanuric acid	Xylene (xylol or dimethyl benzene)
Trichloromonofluoromethane (Fluorotrichloromethane)	Xylidene (2,4-dimethylamino-benzene)
Trichloronaphthalene	Xylol (xylene)
2,4,5-Trichlorophenoxyacetic acid and salts	
1,2,3-Trichloropropane	Yttrium
1,3,5-Trichloro-s-triazine-2,4,6-trione	
Tridymite	Zinc
Triethylamine	Zinc fume
Trifluoromonobromomethane	Zinc oxide
Trimellitic anhydride	Zirconium compounds
2,4,7-Trinitro-9-fluorenone	Zirconium oxide

Table 9.13 Methods for sampling and analysis of a range of air pollutants

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Abate	F (5 µm 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 ₂ O ₃)	F (5 µm PVC)	250	2000	G
4-Aminodiphenyl	F (0.8 µm MCEF)	540	4000	C
2-Aminoethanol, see Ethanolamine				
2-Aminopyridine				
Ammonia	I	5	1000	C
	OT	1	100	LDDT
	P			PC
Ammonium chloride—fume	F (0.8 µm MCEF)	100	2000	C
Ammonium sulphamate (ammate)	F (5 µm 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 µm MCEF)	360	1500	AAS
ANTU (α-naphthylthiourea)	F (0.8 µm MCEF)	300	1500	GLC
Arsenic and compounds (as As)	F (0.8 µm MCEF)	90	2000	AAS
Arsenic trioxide production (as As)		30	1700	C
Arsine	CT	10	200	AAS
Asbestos	F (0.8 µm MCEF)	100	1500	(microscopic fibre count)
Asphalt (petroleum) fumes	F (2 µm PVC)	250	2000	G
Azinophos methyl	I	100	1000	GLC
Barium (soluble compounds)	F (0.8 µm MCEF)	180	1500	AAS

Table 9.13 Cont'd

Substance	Sampling method ⁽¹⁾	Min. sample size ⁽²⁾ (l)	Suggested max. sample rate ⁽³⁾ (ml/min)	Analytical technique ⁽⁴⁾
Benzene	CT	12	200	GLC
	OT	2		LDDT
Benzidine production	F (0.8 µm MCEF)	480	4000	C
<i>p</i> -Benzoquinone, see Quinone				
Benzoyl peroxide	I	30	1000	C
Benzo(a)pyrene				
Benzyl chloride	CT	10	200	GLC
Beryllium	F (0.8 µm MCEF)	270	1500	AAS (30 min allowed at 0.025 mg/m ³)
Biphenyl	CT	30	200	GLC
Bismuth telluride	F (0.8 µm MCEF)	100	1500	AAS
Boron oxide	F (2 µm 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, see 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, see 2-Butoxyethanol				
tert-Butyl chromate (as CrO ₃)	F (0.8 µm MCEF)	23	1500	C
<i>n</i> -Butyl glycidyl ether	CT	10	200	GLC
<i>n</i> -Butyl lactate	F (0.8 µm 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 µm MCEF)	15	1000	AAS
Cadmium, fume (as Cd)				
Cadmium oxide fume (as Cd)	F (0.8 µm MCEF)	25	1500	AAS
Calcium arsenate (as As)	F (0.8 µm MCEF)	500	1500	AAS
				C
Calcium carbonate/marble	F			G (nuisance dust)
Calcium oxide	F (0.8 µm MCEF)	85	1500	AAS
Camphor, synthetic	CT	10	200	GLC
Caprolactam				
dust	F (0.8 µm MCEF)			GLC
vapour	I			GLC
Carbaryl (Sevin®)	F (GF)	90	1500	C (do not use Tenite holder)

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Carbon black	F (2 µm 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 µm MCEF)	15	1000	GLC
Chlorinated diphenyl oxide	F (0.8 µm 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 µm MCEF)	100	1500	GLC
	OT	50	200	GLC
Chlorodiphenyl (54% chlorine)	F (0.8 µm 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 µm MCEF)	90	1500	AAS
Chromic acid and chromates (as Cr)	F (5 µm PVC)	22.5	1000	C
Chromium, soluble chromic and chromous salts (as Cr)	F (0.8 µm MCEF)	90	1500	AAS

Table 9.13 Cont'd

Substance	Sampling method ⁽¹⁾	Min. sample size ⁽²⁾ (l)	Suggested max. sample rate ⁽³⁾ (ml/min)	Analytical technique ⁽⁴⁾
Coal tar pitch volatiles, see Particulate polycyclic aromatic hydrocarbons (PPAH), as benzene solubles				
Cobalt metal, dust and fume (as Co)	F (0.8 µm MCEF)	720	1500	AAS
Copper fume	F (0.8 µm MCEF)	720	1500	AAS
dusts and mists (as Cu)	F (0.8 µm MCEF)	90	1500	AAS
Corundum (Al ₂ O ₃)	F			G (nuisance dust)
Cotton dust (raw)	F (5 µm 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 + I (0.8 µm 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-n-Dibutylaminoethanol				
Dibutyl phosphate				
Dibutyl phthalate	F (0.8 µm 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
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

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Dichloroethyl ether	CT	15	1000	GLC
Dichloromethane, <i>see</i> 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, <i>see</i> 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, <i>see</i> Ethyl ether				
Diethyl phthalate	F (0.8 µm MCEF)	30	1000	GLC
Difluorodibromomethane	CT	10	200	GLC
Diglycidyl ether	CT	15	1000	GLC
Dimethoxyethane, <i>see</i> Methylal				
Diisobutyl ketone	CT	12	200	GLC
Diisopropylamine	I	15	200	C
Dimethyl acetamide	ST	50	1000	GLC
Dimethylamine	ST	50	200	GLC
Dimethylaminobenzene, <i>see</i> Xylidene				
Dimethylaniline (<i>N,N</i> -dimethylaniline)	CT	20	200	GLC
	ST	5	200	
Dimethylbenzene, <i>see</i> Xylene				
Dimethyl-1,2-dibromo-2-dichloroethyl phosphate, <i>see</i> Dibrom®				
Dimethylformamide	ST	50	1000	GLC
2,6-Dimethyl-4-heptanone, <i>see</i> 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

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Di-sec, Octyl phthalate (di-2-ethylhexylphthalate)	CT	30	200	GLC
Dust, inert or nuisance respirable total	F (5 µm PVC)	102	1700	G (use cyclone but no Tenite holders)
Emery	F			G (nuisance dust)
Endrin	I	100	1000	GLC
Epichlorohydrin	CT	20	200	GLC
EPN	F (GF)	120	1500	GLC
1,2-Epoxypropane, see Propylene oxide				
2,3-Epoxy-1-Propanol, see Glycidol				
Ethanethiol, see 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, see 1,2-Dibromomethane				
Ethylene dichloride, see 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, see 1,1-Dichloroethane				
N-Ethylmorpholine	CT	10	200	GLC
Ferbam	F (0.8 µm MCEF)	150	1500	C
Ferrovandium dust	F (0.8 µm 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

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method</i> ⁽¹⁾	<i>Min. sample size</i> ⁽²⁾ (l)	<i>Suggested max. sample rate</i> ⁽³⁾ (ml/min)	<i>Analytical technique</i> ⁽⁴⁾
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, <i>see</i> 2-Ethoxyethanol				
Graphite (synthetic)	F			G (nuisance dust)
Guthion®, <i>see</i> 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	CT	10	200	GLC
Hexachloroethane				
Hexachloronaphthalene	F (0.8 µm 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 µm 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 µm MCEF)	300	1500	C
Iodine	I	15	1000	C
Iron oxide fume (NOC)	F (0.8 µm MCEF)	30	1500	AAS
Iron pentacarbonyl	F (0.8 µm MCEF)	175	1500	AAS
Iron salts, soluble (as Fe)	F (0.8 µm MCEF)	4	1500	AAS

Table 9.13 Cont'd

Substance	Sampling method ⁽¹⁾	Min. sample size ⁽²⁾ (l)	Suggested max. sample rate ⁽³⁾ (ml/min)	Analytical technique ⁽⁴⁾
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 µm MCEF)	100	4000	AAS
Limestone	F			G (nuisance dust)
Lindane	F + I	90	1500	GLC
Lithium hydride	F (0.8 µm 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 µm MCEF)	150	1500	AAS
Malathion	F (GF)	120	1000	GLC
	I			
Manganese and compounds (as Mn)	F (0.8 µm MCEF)	22.5	1500	AAS (1500 cc/min only)
Manganese cyclopentadienyl tricarbonyl (as Mn)	F (0.8 µm 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
Methyl bromide	CT	11	1000	GLC (2 large charcoal tubes in series)
Methyl butyl ketone, see 2-Hexanone				
Methyl cellosolve, see 2-Methoxyethanol				
Methyl cellosolve acetate, see Ethylene glycol monomethyl ether acetate				
Methyl chloroform (1,1,1-trichloroethane)	CT	6	200	GLC
Methylcyclohexane	CT	4	200	GLC (for methylcyclohexane)

Table 9.13 Cont'd

Substance	Sampling method ⁽¹⁾	Min. sample size ⁽²⁾ (l)	Suggested max. sample rate ⁽³⁾ (ml/min)	Analytical technique ⁽⁴⁾
Methylcyclohexanol	CT	10	200	GLC
o-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), see 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, see 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, see 2-Pentanone				
α-Methyl styrene	CT	3	200	GLC
Molybdenum (as Mo)				
soluble compounds	F (0.8 μm MCEF)	90	1500	AAS
insoluble compounds	F (0.8 μm 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
β-Naphthylamine				
Nickel carbonyl	I	200	2000	AAS
Nickel metal				
Nickel, soluble compounds (as Ni)	F (0.8 μm 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)
p-Nitroaniline	ST	15	1000	GLC
Nitrobenzene	ST	50	1000	GLC
p-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

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
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 µm MCEF)	30	1000	GLC
Octane	CT	4	200	GLC
Oil mist, mineral	F (0.8 µm 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 µm 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 µm SM)	720	1500	G (use GF prefilter)
Pentachloronaphthalene	F + I (GF)	250	1500	GLC
Pentachlorophenol	F (0.8 µm 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
p-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
Phosphine	F (0.8 µm MCEF)	5	50	C (GF prefilter)
Phosphoric acid	F (0.8 µm 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 µm MCEF)	100	1500	GLC
Picric acid				
Pival® (2-pivalyl-1,3-indandione)	I	100	1000	GLC
Plaster of Paris	F			G (nuisance dust)

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method</i> ⁽¹⁾	<i>Min. sample size</i> ⁽²⁾ (l)	<i>Suggested max. sample rate</i> ⁽³⁾ (ml/min)	<i>Analytical technique</i> ⁽⁴⁾
Platinum, soluble salts (as Pt)	F (0.8 µm MCEF)	720	1500	AAS
Polychlorobiphenyls, <i>see</i> Chlorodiphenyls				
Polytetrafluoroethylene decomposition products				<i>see</i> Fluoride procedure
Propane				
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, <i>see</i> Methyl acetylene				
Pyrethrum	I	100	1000	GLC
Pyridine	CT	100	1000	GLC
Quinone	I	100	1000	C
RDX	F (0.8 µm MCEF)	150	1500	UV
Rhodium (as Rh)				
metal fume and dusts	F (0.8 µm MCEF)	720	1500	AAS
soluble salts	F (0.8 µm MCEF)	370	1500	AAS
Ronnel	I	100	1000	GLC
Rosin core solder pyrolysis products (as formaldehyde)	I	25	1000	C
Rotenone (commercial)	I	60	1000	UV
Rouge	F			G (nuisance dust)
Selenium compounds (as Se)	F (0.8 µm MCEF)	360	1500	AAS
Selenium hexafluoride (as Se)	I	60	1000	AAS
Sevin® (<i>see</i> carbaryl)				
Silica				
respirable	F (5 µm 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 µm MCEF)	45	1500	
Sodium fluoroacetate				
Sodium ⁺ oxide	I	350	1000	C (for titration)
Starc	F			G (nuisance dust)
Stibine	CT	100	200	AAS
				C
Stoddard solvent	CT	3	200	GLC
Strychnine	F (0.8 µm MCEF)	360	1500	UV
Styrene, monomer (phenylethylene)	CT	1	200	GLC

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾</i> (l)	<i>Suggested max. sample</i> <i>rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Succinaldehyde, see Glutaraldehyde				
Sucrose	F			G (nuisance dust)
Sulphur dioxide	OT	1	20	LDDT
	F + I (0.8 µm MCEF)	100	2000	C (titration)
	P			PL
Sulphur hexafluoride	I	15	1000	UV
Sulphuric acid	F (0.8 µm 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 µm MCEF)	720	1500	AAS
TEDP	I	100	1000	GLC
Teflon® decomposition products				See Fluoride procedure
Tellurium and compounds (as Te)	F (0.8 µm MCEF)	670	1500	AAS
Tellurium hexafluoride (as Te)	CT	360	1000	AAS (MCEF prefilter)
TEPP	I	100	1000	GLC
Terphenyls	F (0.8 µm 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 µm MCEF)	60	2000	C
Tetrahydrofuran	CT	9	200	GLC
Tetramethyl lead (as Pb)	CT	60	1000	AAS
	F + I (0.8 µm MCEF)	60	2000	C
Tetramethyl succinonitrile	CT	50	1000	GLC
Tetranitromethane	I	250	1000	GLC
Tetryl (2,4,6-trinitrophenylmethyl nitramine)	F (0.8 µm MCEF)	100	1500	C
	F (0.8 µm MCEF)	540	1500	AAS
Thallium, soluble compounds (as Tl)	F (0.8 µm MCEF)	180	1500	AAS
Thiram	F (0.8 µm MCEF)	180	1500	C
Tin, inorganic compounds, except SnH ₄ and SnO ₂ (as Sn)	F (0.8 µm MCEF)	240	1000	AAS
Tin, organic compounds (as Sn)				
Tin oxide (as Sn)	F			G (nuisance dust)
Titanium dioxide (as Ti)	F (0.8 µm 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 µm MCEF)	100	1500	GLC
1,1,1-Trichloroethane, see Methyl chloroform				
1,1,2-Trichloroethane	CT	10	200	GLC

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
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 µm MCEF)	360	1500	C
Triorthocresyl phosphate	F (0.8 µm MCEF)	100	1500	GLC
Triphenyl phosphate	F (0.8 µm MCEF)	100	1500	GLC
Tungsten and compounds (as W)				
soluble				
insoluble				
Turpentine	CT	10	200	GLC
Uranium, natural (as U)				
soluble	F (0.8 µm MCEF)	45	1500	(fluorometric)
insoluble compounds	F (0.8 µm MCEF)	45	1500	(fluorometric)
Vanadium (V ₂ O ₅) (as V)				
dust	F (0.8 µm 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, see Acrylonitrile				
Vinylidene chloride				
Vinyl toluene	CT	10	200	GLC
VM and P naphtha				
Warfarin				
Welding fumes (total particulate) (NOC)	F (0.8 µm 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 µm MCEF)	500	1500	AAS

Table 9.13 Cont'd

<i>Substance</i>	<i>Sampling method⁽¹⁾</i>	<i>Min. sample size⁽²⁾ (l)</i>	<i>Suggested max. sample rate⁽³⁾ (ml/min)</i>	<i>Analytical technique⁽⁴⁾</i>
Zinc chloride fume	F (0.8 µm MCEF)	25	1500	AAS
Zinc oxide fume	F (0.8 µm MCEF)	360	1500	AAS (also X-ray diffraction)
Zinc stearate	F (PVC)			G (nuisance dust)
Zirconium compounds (as Zr)	F (0.8 µm MCEF)	720	1500	AAS

Based on *Sampling and Analytical Guide for Airborne Health Hazards*, Du Pont Company, Applied Technology Division.

⁽¹⁾ *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

⁽²⁾ 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.

⁽³⁾ The maximum flowrate recommended for the given collection method. Sampling may be done at lower rates as long as minimum sample size is met.

⁽⁴⁾ *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 ₃ Colorimetric Readout
UV	Ultraviolet

Sampling strategies

The scheme in Figure 9.1 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:

$$\text{Minimum volume (m}^3\text{)} = \frac{10 \times \text{sensitivity of analytical method (mg)}}{\text{suitable hygiene standard (mg/m}^3\text{)}}$$

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, σ = standard deviation. If σ is unknown from previous results, an estimate can be made from a few samples and the maximum acceptance limit is hygiene standard ($k \times$ range), where k is obtained from Table 9.14. 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.

Table 9.14 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

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 $1\text{--}2 \times$ hygiene standard
 once per quarter if $0.5\text{--}1$ or $2\text{--}4 \times$ hygiene standard
 once per year if $0.1\text{--}0.5$ or $4\text{--}10 \times$ 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 must be met sampling should be considered when exposures exceed 0.1 CL. (The frequencies refer to monitoring the entire shift period for every 10 employees.) Table 9.15 offers guidance for monitoring strategies for compounds assigned OELs (Chapter 4) through legislative requirements.

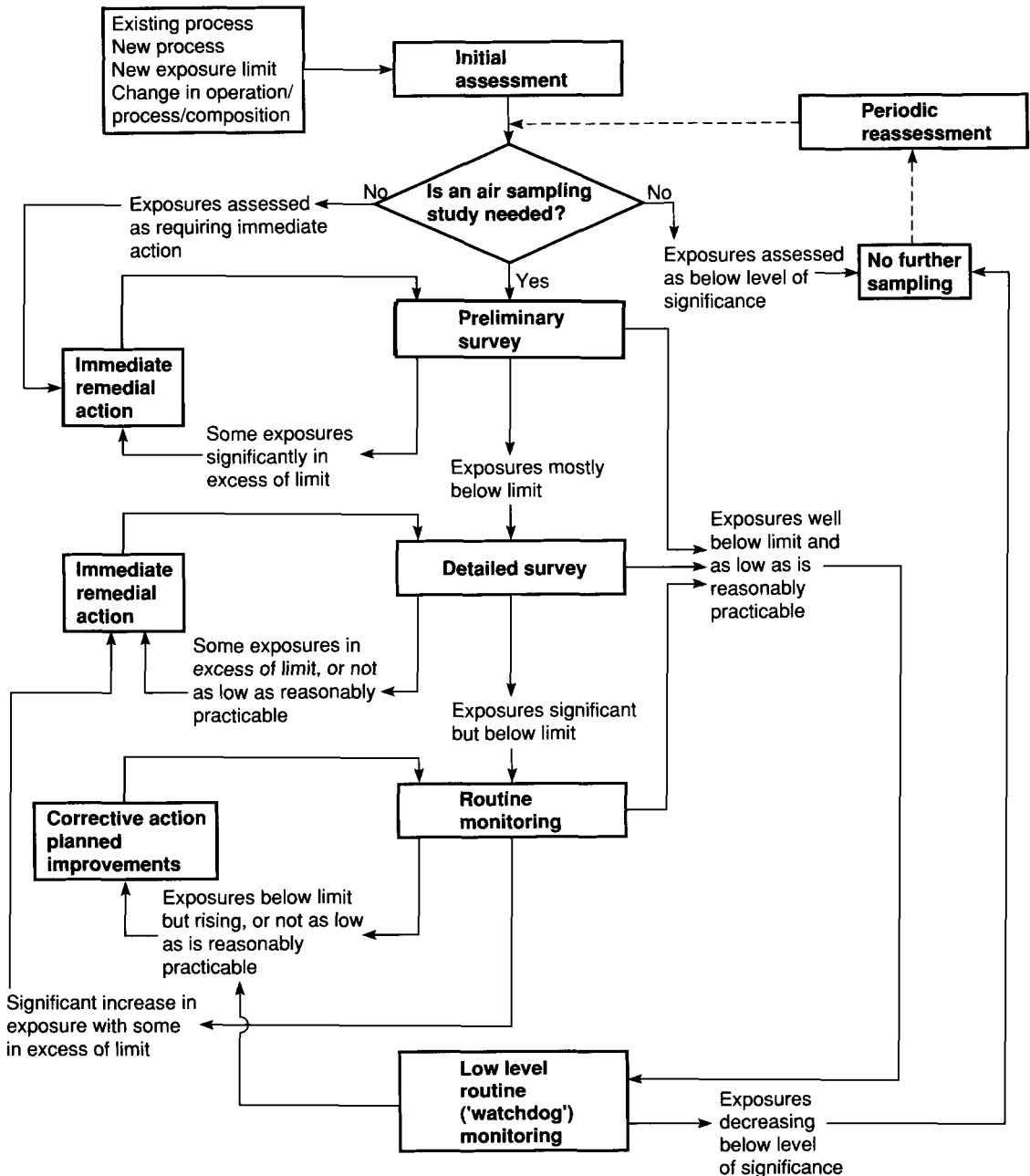


Figure 9.1 Monitoring strategies flow diagram

Table 9.15 Recommended guidance for routine monitoring

<i>Survey</i>	<i>Results</i>	<i>Action</i>
Preliminary	All $<0.1 \times \text{OEL}^{(1)}$	None if exposures are as low as reasonably practical.
	$0.1 - 1.5 \times \text{OEL}$	Investigate and carry out a more detailed survey.
	Some $>1.5 \times \text{OEL}$	Investigate, take remedial action and repeat survey.
Detailed	All $<0.25 \times \text{OEL}$	None if exposure is as low as reasonably practical.
	$\leq 1.25 \times \text{OEL}$	Investigate, take remedial action and repeat survey.
	Arithmetic mean $<0.5 \times \text{OEL}$	Consider routine monitoring and the appropriate frequency.
	Mean $>0.5 \times \text{OEL}$ (or with individual results scattered above the limit)	Investigate, assess control measures, improve where possible, repeat survey and consider routine monitoring.
Routine	All	Check values, mean, range, etc. Is there compliance with OEL and if so what is confidence?
	Differ significantly from previous survey	Investigate, consider remedial action detailed survey or change protocols.

⁽¹⁾ 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.

Radioactive chemicals

The main chemical elements are listed in Chapter 14. 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 10.1). 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 10.1 Nuclear composition of selected isotopes

<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 or unsealed. Examples of the former are smoke detectors and electrical devices for producing radiation, i.e. the radiation can be switched off.

Hazards

The chemistry, and hence hazards, of 'hot', or radioactive, elements parallels that of their 'cold' isotopes. However, the radiation poses additional toxicity hazards. A qualitative classification of selected isotopes in terms of their toxicity is given in Table 10.2. 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,

Table 10.2 Classification of isotopes according to relative radiotoxicity per unit activity

The isotopes in each class are listed in order of increasing atomic number

Very high toxicity	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.
High toxicity	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.
Moderate toxicity	*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.
Slight toxicity	H-3, *Be-7, C-14, F-18, *Cr-51, Ge-71, *Ti-201.

* Gamma-emitter.

Table 10.3 Effects of acute exposures to X- and γ -radiation

<i>Dose (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 ₅₀ (see Ch. 4), death occurring within 30 days. Erythema (reddening of skin) within 3 weeks.
7–10	LD ₁₀₀ , death occurring within 10 days.

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 10.3.

Types of radiation

The nature of the radioactive decay is characteristic of the element and 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. α -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 γ -radiation or X-radiation. α -Particles have a velocity about one-tenth that of light with a range in air of 3–9 cm. Because of their relatively 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 α -particles within tissues may cause intense local ionization.

2. β -Rays comprise electrons of velocity approaching that of light with a range of several metres and an energy of 0–4 MeV. β -Particles of <0.07 MeV do not penetrate the epidermis whereas those >2.5 MeV penetrate 1–2 cm of soft tissue. Thus β -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 γ -rays. About 1 mm of aluminium is needed to stop these particles. Most β -emissions are accompanied by γ - or X-radiation and result in transformation into the element of one atomic number higher or lower but with the same atomic mass.

3. γ -Radiation is similar to, but shorter in wavelength than, X-rays and is associated with many α - or β -radiations. γ -Radiation does not transform isotopes/elements. Like X-rays, γ -rays are very penetrating; they are capable of penetrating the whole body and require heavy shielding, e.g. γ -rays from ^{60}Co penetrate 15 cm steel.

4. X-Radiation like γ -radiation is electromagnetic in nature. It can be emitted when β -particles react with atoms, but is more often electrically generated by accelerating electrons in a vacuum tube. Obviously, 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 α -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. γ -radiation from potassium-42 has about four times the energy of γ -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 on to 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 European Community are summarized in Table 10.4.

Table 10.4 EC radiation dose limits

Annual dose (sum of external and internal radiation)		<i>Employee aged >18 years</i>	<i>Trainee aged <18 years</i>	<i>All others except as IV, V</i>
I Whole body		50 mSv	15 mSv	5 mSv
II Individual organ ⁽¹⁾		500 mSv	150 mSv	50 mSv
III Lens		150 mSv	45 mSv	15 mSv
<hr/>				
Dose over 3-month consecutive period				
IV Woman of child-bearing capacity		13 mSv		
Dose over term of pregnancy				
V Abdomen of pregnant woman		10 mSv		

⁽¹⁾ Includes tissues, body extremity or area of skin $\leq 100 \text{ cm}^2$; excludes eye.

In the UK, annual doses of 15 mSv, or any case of suspected overexposure, must be investigated and recorded. Three-month doses $> 30 \text{ mSv}$ must be reported to the HSE. 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.

Table 10.5 Approximate half-thickness values for a selection of shield materials and γ -emitters

Nucleide	Half-life	γ -energy (MeV)	<i>H-TV (cm)</i>		
			Concrete	Steel	Lead
^{137}Cs	27 years	0.66	4.82	1.63	0.65
^{60}Co	5.24 years	1.17–1.33	6.68	2.08	1.20
^{198}Au	2.7 days	0.41	4.06	—	0.33
^{192}Ir	74 days	0.13–1.06	4.32	1.27	0.60
^{226}Ra	1622 years	0.047–2.4	6.86	2.24	1.66

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 α - and β -emitters and whole-body monitoring for γ -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 α - and β -particles pose few problems (the former can be absorbed by, e.g., paper and the latter by 1 cm Perspex) γ - 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 γ -rays are exemplified by Table 10.5.

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 10.6.

Table 10.6 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 work with ionizing radiation).
Conduct work in designated controlled areas (e.g. in UK these are areas in which instantaneous dose rates $> 7.5 \mu\text{Sv}$ occur, or where employees may exceed 15 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 of 30% of relevant hygiene standard).
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 50 years). Monitor background contamination periodically using equipment that has been checked by qualified persons and keep records of levels (e.g. for 2 years).

Table 10.6 Cont'd

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 50 years.)

Maintain high standards of personal hygiene and housekeeping.

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, lockers for clean and dirty clothing.

Administration and systems of work

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.

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.

Table 11.1 Some considerations in reaction process selection and design

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?

Table 11.2 Chemical process hazard identification

Materials and reaction	<p>Identify all hazardous process materials</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 non-condensable materials?</p>
General process specification	<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>

Design

Consult flow sheets/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 11.1. Subject the proposals to detailed scrutiny, as in Table 11.2 or using a HAZOP study, fault tree analysis etc. for both the planned operation and anticipated major deviations from normal operation (Table 11.3). Thus, the HAZOP technique relies on asking 'what happens if' flow stops/too fast etc. Typical key words are listed in Table 11.4.

Table 11.3 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 shut down 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?

Table 11.4 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.

Guide words for HAZOP studies

<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 11.5 Electrical zoning

Classification of hazard areas according to the probability of a flammable concentration of vapour occurring (to BS 5345 Part 1)

Zone 0	Area in which an explosive gas–air mixture is continuously present, or present for long periods
Zone 1	Area in which an explosive gas–air mixture is likely to occur in normal operation
Zone 2	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
Safe area	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

Vapour source	Extent of classified area	Area classification
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 (b) Within 2 m in all other directions from point of discharge	Fixed electrical equipment should not be installed 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 (b) Vertically and horizontally between 2 m and 4 m from the points of connection or disconnection	Zone 1 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 bunded 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.

Equipment layout is also crucial, with consideration given to:

- Spacing distances (e.g. between storage tanks, between hazardous areas and admin block/control rooms). Distances to public roads.
- Electrical zoning (refer to Table 11.5).
- Access/ergonomics: emergency escape and access.
- Lighting.
- Drainage.

Spacing distances

Adequate spacing 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 or effects on site of fire, explosion, toxic release or similar incident. Selected sources of information are summarized in Table 11.6. A typical example is given in Table 11.8 subject to the requirement of Table 11.7.

Table 11.6 Selected sources of spacing distances with hazardous chemicals (see Bibliography)

Preliminary minimum distances	
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
Electrical area classification distances	<i>Process Plant Layout</i> pages 568–577
Distances for storage of explosives	<i>Explosive and Toxic Hazard Materials</i> page 370 (Meidl, 1970)
	<i>Safe Handling Requirements during Explosive, Propellant and Pyrotechnic Manufacture</i> (HSE, SIR 31)
General recommendations for spacing	<i>General Recommendations for Spacing in Refineries, Petrochemical Plants, Gasoline Plants, Terminals, Oil Pump Stations and Offshore Properties</i> (Oil Insurance Association, No. 361)
'Consultation' distances (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)
Minimum recommended spacing distances	
Highly flammable liquids	<i>Storage of Highly Flammable Liquids</i> (HSE, CS2)
Liquefied petroleum gas	<i>Storage and Use of LPG at Fixed Installations</i> (HSE, CS5)
	<i>Storage and Use of LPG at Metered Estates</i> (HSE, CS11)
	<i>Storage and Use of LPG on Construction Sites</i> (HSE, CS6)
	<i>Keeping of LPG in Cylinders and Similar Containers</i> (HSE, CS4)
Distances for storage and handling of dangerous chemicals	<i>Storage and Handling of Organic Peroxides</i> (HSE, CS21)
	<i>Storage of Packaged Dangerous Substances</i> (HSE, HS(G) 71)

Table 11.7 Minimum separation distances for open air LPG stores

<i>Total LPG storage including nominally empty cylinders</i> (kg)	<i>Minimum separation distance to huts, site boundaries or fixed sources of ignition</i>	
	<i>from the nearest cylinder (where no radiation wall is provided)</i> (m)	<i>from radiation wall (where provided)</i> (m)
50 up to 300	1	nil
>300 up to 1000	3	1
>1000 up to 4000	4	1

Table 11.8 Maximum quantity of LPG in columns of stacks

<i>LPG content of any cylinder</i> (kg)	<i>LPG content of any vertical column of stack</i>	
	<i>Palletized</i> (kg)	<i>Non-palletized</i> (kg)
up to 6	35	30
>6 up to 15	75	45
>15 up to 20	80	50
>20 up to 55	110	55

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.

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 fan and the air inlet require careful consideration to minimize operator exposure (Figure 11.1). 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.

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.

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

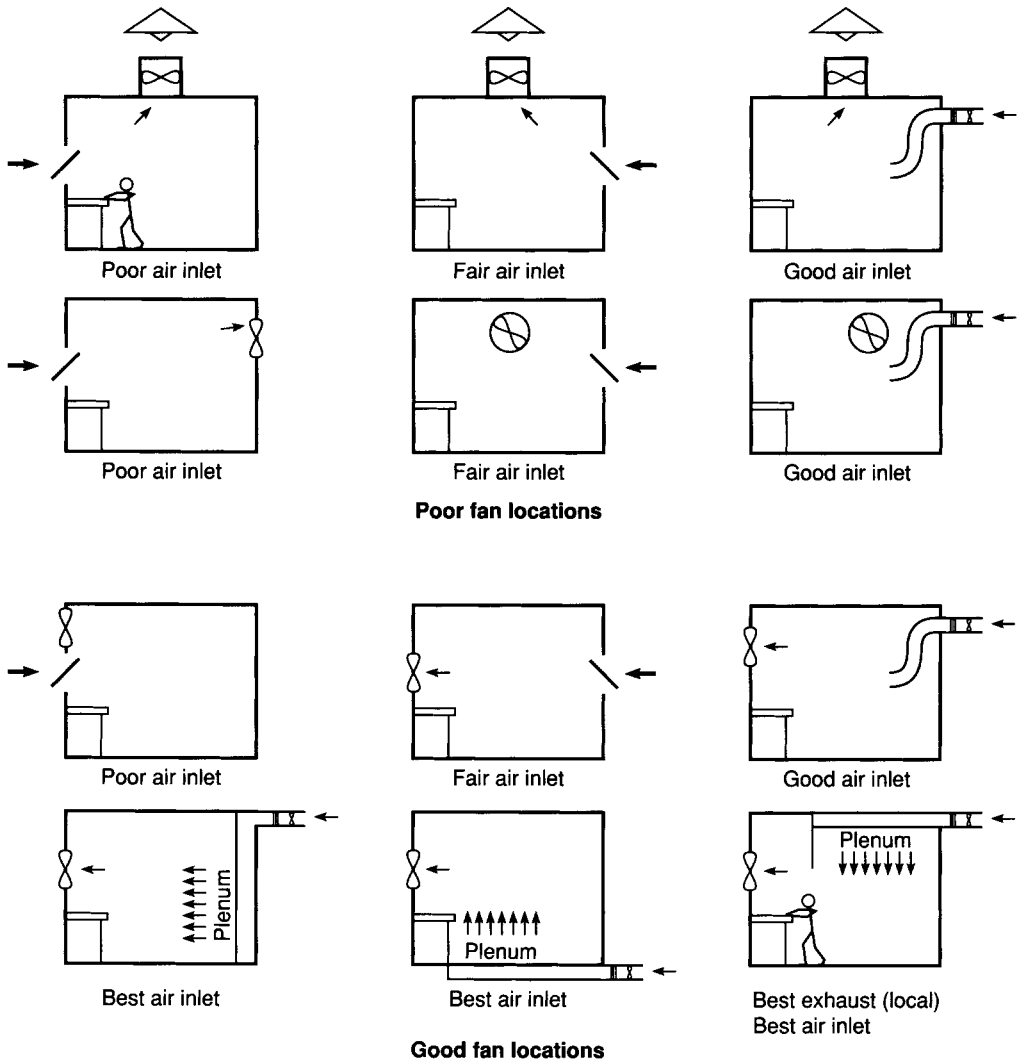


Figure 11.1 Dilution ventilation: inlet air may require tempering according to outside conditions

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 282).

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. 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 11.1).

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 11.9. Since velocity falls off rapidly with distance from the face of the hood, as shown in Figure 11.2, any source of dust should be within one hood 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 11.10.

Table 11.9 Range of capture velocities

<i>Condition of dispersion of contaminant</i>	<i>Examples</i>	<i>Capture velocity (m/s)</i>
Released with practically no velocity into quiet air	Evaporation from tanks Degreasing vats etc.	0.25–0.51
Released at low velocity into moderately still air	Spray booths Intermittent container filling Low-speed conveyor transfers Welding Plating Pickling	0.51–1.02
Active generation into zone of rapid air motion	Spray painting in shallow booths Barrel filling Conveyor loading Crushers	1.02–2.54
Released at high initial velocity into zone of very rapid air motion	Grinding Abrasive blasting Tumbling	2.54–10.2

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.

Table 11.10 Typical recommended transport velocities

Material, operation or industry	Minimum transport velocity	
	(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
Rubber dust		
fine	12.7	2500
coarse	20.3	4000

Table 11.10 Cont'd

Material, operation or industry	Minimum transport velocity	
	(m/s)	(ft/min)
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

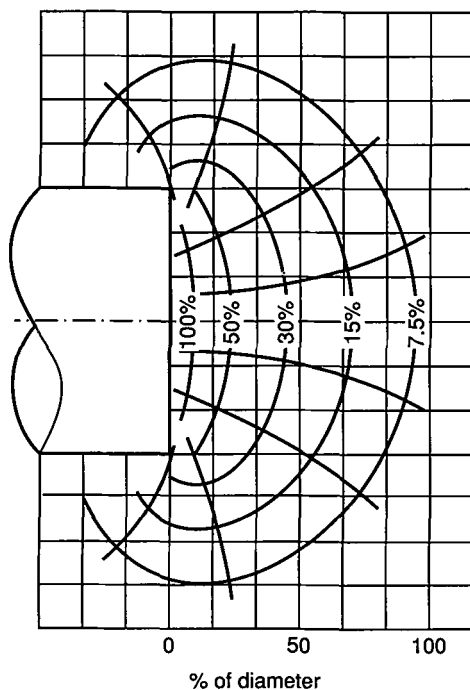


Figure 11.2 Reduction in air velocity with distance from captor hood (distance given as % of hood diameter)

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

Safe handling of chemicals demands a combination of 'hardware' and 'software' such as operating procedures, staff selection and training. Systems of work will generally include:

- The selection and supervision of personnel.
- Planning and coordination of all activities – in particular those involving different sections, departments or tradesmen.
- Training and instruction of the workforce. Retraining.
- Provision of operating instructions and procedures.
- Provision of adequate supervision.
- Inspection, testing, maintenance and replacement of equipment as necessary.
- General conditions of work.

A checklist is given in Table 11.11.

Table 11.11 Safety systems in operation

Access	<i>System for</i> Control of access to site; maintenance of security Designation of restricted areas, e.g. containing flammable materials, 'eye protection' zones, 'hearing protection' zones, radiological hazards, microbiological hazards Ensuring freedom from obstruction of roads, stairs, gangways, escape routes Control of vehicles
Communication systems	<i>Maintenance of adequate</i> Written instructions, maintenance procedures etc. Log books, recipe sheets, batch sheets Identification of vessels, lines, valves etc. Intershift communication and records System for reporting and follow-up of Plant defects Process deviations Hazardous occurrences ('near misses') Accidents: minor/major injury and/or material loss Warnings, notices Notices relating to specific hazards Notices relating to temporary hazards (and their subsequent removal) (See also permit-to-work systems and operating procedures) Alarms; emergency communications
Control of contractors	Familiarization with plant hazards, rules and safety practices, security Clear delineation of work, responsibilities and handover (See also maintenance, permit-to-work systems, personal protection, site restrictions, access, modifications, personal hygiene etc.)
First aid provisions	<i>Maintenance of adequate provision for</i> Emergency showering Eye-washing Decontamination from chemicals (and antidotes if relevant) First aid (equipment, materials, trained personnel) and resuscitation

Table 11.11 Cont'd

Housekeeping	<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>
Inspection and testing (including cleaning/ 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>
Maintenance	<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"> Flame cutting/welding (or soldering, brazing etc.) Line-breaking Electrical work – certain classifications Equipment removal, e.g. to workshop Work on roof/at heights Isolation of safety services Excavations Introduction of non-flameproof electrical equipment into restricted area Mechanical isolation, e.g. conveyors, lifts Confined space entry Radioactive areas Microbiological ventilation systems, fume cupboards etc. Other unusual/non-routine situations <p>Provision for trained persons to be present/on call, e.g. rescue, first aid, fire-fighting</p> <p>Instruction and training of personnel</p> <p>Maintenance of guards on machinery, open vessels, handrails, screens at sampling/drumming-up points etc. and on glass equipment</p> <p>Use of sparkproof tools where appropriate</p> <p>Record-keeping</p> <p>Inspections, e.g. pressure systems, trips, relief devices, guards, lighting (see inspection and testing)</p>
Materials	<p><i>Maintenance of adequate procedures for</i></p> <p>In bulk, e.g. checks on tanker contents, earthing and bonding, identification of receiving vessel</p> <p>In small containers, e.g. carboy handling, cylinder unloading</p> <p>Despatch of materials</p> <ul style="list-style-type: none"> Inspection of tankers, carboys, cylinders etc. prior to filling Identification and labelling of materials; drive instructions <p>Use of earthing clips on portable containers of flammable liquids</p>
Modifications to plant or process	<p><i>System for</i></p> <p>Control of changes in raw materials</p> <p>Formal approval for plant/process changes</p> <p>Hazard and operability study prior to implementation (repeat when in use)</p> <p>Updating of all operating instructions, notices, procedures</p> <p>Removal/isolation of obsolete plant/lines</p> <p>Control of changes in personnel (see training)</p>

Table 11.11 Cont'd

Monitoring and follow-up	<p><i>Systems for monitoring</i></p> <ul style="list-style-type: none"> Working environments <ul style="list-style-type: none"> Toxic contaminants Temperature Noise Lighting Vibration Ionizing radiation Occupational health <ul style="list-style-type: none"> Pre-employment medical for selection and establishment of base levels Working conditions in specific areas Employees' routine medicals, exposure profiles Biological monitoring where appropriate
Operating procedures	<p><i>Systems include</i></p> <ul style="list-style-type: none"> Provision of clearly written operating instructions, accessible to operators, referring to numbered/identified plant items, covering <ul style="list-style-type: none"> Start-up and shutdown Normal operation, draining, purging, excursions etc. Operation at high or low rates Emergency shutdown, service failures etc. Procedures for non-routine operations, e.g. clearance of blockages, reprocessing of materials, temporary process alteration Pressure testing, sampling, chemical and atmospheric testing Established procedures for draining, purging, venting, isolating, testing and inspection prior to opening/entering/maintaining plant (see permit-to-work systems, maintenance) Quality control on raw materials, materials in process, products and wastes Materials control to enable losses, over-use, under-use or accumulations of materials to be detected; control of quantities in storage
Permit-to-work systems	<p>See under 'Maintenance'</p> <ul style="list-style-type: none"> Entry into confined spaces (e.g. vat, vessel, flue, sewer, boiler or similar) Use of non-flameproof electrical equipment where flammable liquids/vapours/dusts may arise
Personal hygiene	<p><i>Checks on</i></p> <ul style="list-style-type: none"> Adequacy of washing/showering facilities (location and provision) Skin cleansing, barrier and conditioning cream provision Double locker system
Personal protection	<p><i>Systems to ensure provision of</i></p> <ul style="list-style-type: none"> Overalls: special requirements (flame retardant, antistatic), frequency of laundering Protective clothing: suits, spats, armlets, helmets, gloves for specific applications, footwear (industrial and/or antistatic) Hearing protectors Eye protection: specific provision for various duties Respirators: specific types for different applications
Safety management	<p><i>Systems include</i></p> <ul style="list-style-type: none"> Safety audit system; hazard analysis Checks on the adequacy and location of fire-fighting, emergency rescue and alarm equipment Practice in emergency situations Emergency procedures for <ul style="list-style-type: none"> Fire/explosion Toxic release Serious accidents Spillage Pollution incidents (particularly when manning levels are low, e.g. weekends) Major emergency procedures <ul style="list-style-type: none"> Internal procedures (evacuation, communications, shutdown, damage control) External liaison (fire, police, hospitals, neighbours)

Table 11.11 Cont'd

Site restrictions	<i>Systems include</i> Control over chemicals, containers etc. removal from site (see also waste disposal) Prohibition of eating/drinking except in designated areas Prohibition of smoking, carrying matches/lighters, except in designated areas; arrangements for enforcing this Restriction on employees permitted to drive works transport Control of lone working Control over equipment removal from site
Storage	<i>Procedures for ensuring</i> Identification of all materials Segregation of incompatible materials Good housekeeping Compliance with limits set for stocks of potentially hazardous chemicals Storage, segregation and handling of gas cylinders Display of appropriate warnings/notices
Training: management	<i>Provision for</i> Refresher course on fundamentals of safety, hazard recognition, procedures Participation in hazard and operability studies on existing operations and procedures
Training: operating personnel	<i>Provision for</i> Formal training programme; refresher courses Instruction in hazards associated with the work and safe procedures Introduction of new legislation Instruction and practice in emergency procedures Encouragement/enforcement of use of personal protection Special training needs, e.g. first aid, emergency rescue/fire-fighting
Waste disposal	<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

Maintenance embraces regular inspection, periodic examination by 'competent persons', and repairs. All maintenance on equipment used with chemicals should be properly planned 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. Examples include:

- Entry into confined spaces where there is likely to be a danger from toxic or flammable gases, or oxygen deficiency or enrichment (Table 11.12). Such work requires well rehearsed procedures regulated by a permit. Figure 11.3 identifies the procedures for entry into confined spaces and Table 11.13 lists associated safety requirements with a specimen permit (Figure 11.4).

Table 11.12 Control of oxygen gas

Ease of ignition, combustion rate and combustion temperature all increase when the oxygen content of an atmosphere >21% (Chapter 5).

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 use 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

- Hot work on plant, or in areas where flammable materials are handled, e.g. arc or gas welding (see also Figure 4.4), flame-cutting, use of blow torches, chipping concrete, introduction of non-sparkproof vehicles.

Application of a welding torch or burner to a tank or drum containing flammable material, either as solid, liquid or vapour, 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. A permit-to-work system is required. Refer to Figure 11.5. The vessel must first be rendered safe, e.g. by thorough cleaning, using low-pressure steam or by boiling strong detergent solution, for ≥ 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 11.5).

- Maintenance of apparatus used for microbiology.
- Pipeline breaking.
- Work on high voltage electrical supply, radioactive equipment, roof work such as checking toxic exhaust from ventilation outlets.

(Other examples include 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.)

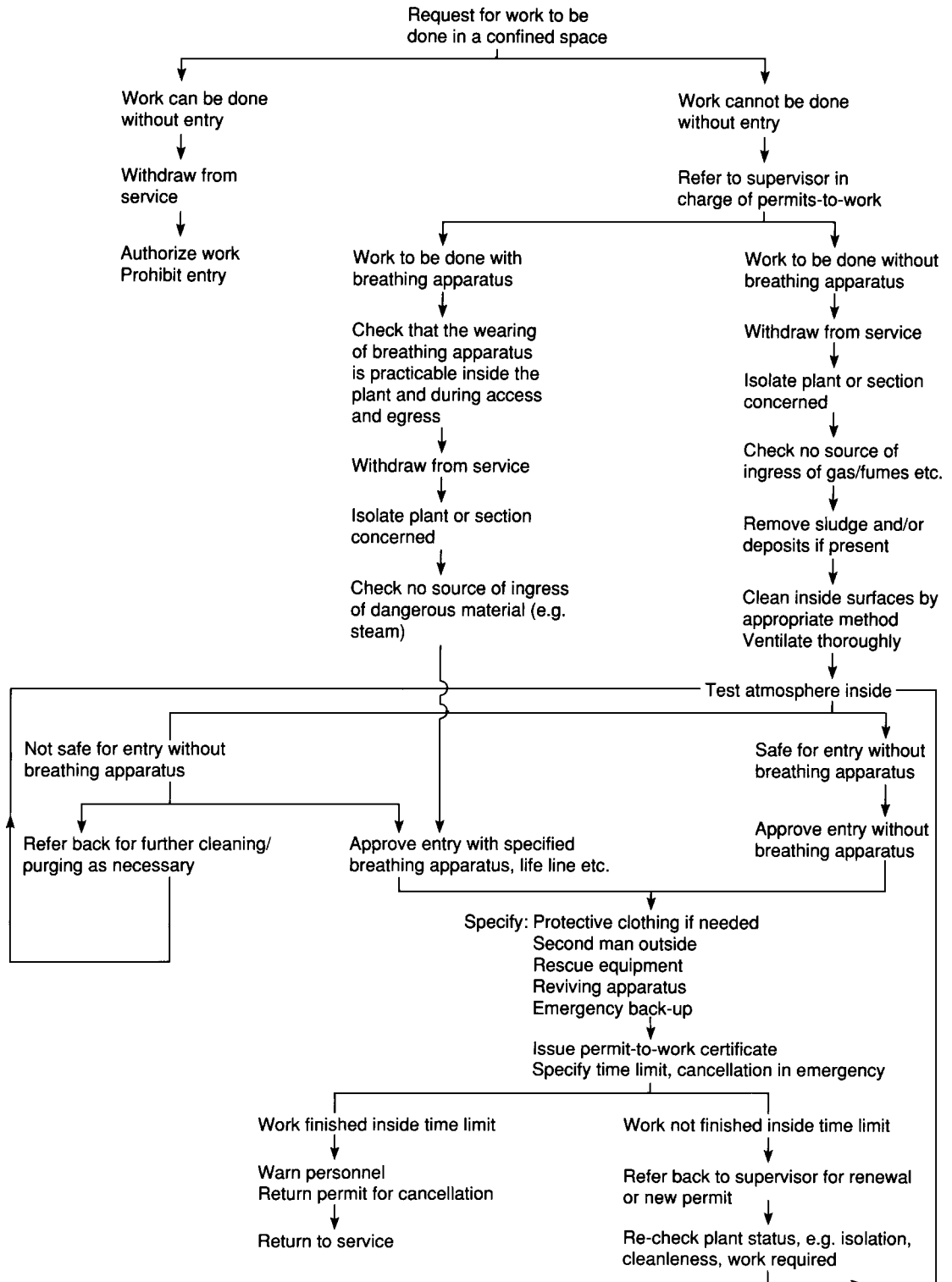


Figure 11.3 Procedure for entry into a confined space

Table 11.13 Entry into confined spaces (see Figure 11.3)

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

A permit should document:

- The person issuing the permit and his position in the company.
- The precise work to be done.
- The risks associated with it.
- Precautions which have been taken and those which need to be observed during the work.
- 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 11.14 and Figure 11.6 illustrates a typical permit-to-work. Safety can only be guaranteed if all participants follow the permit conscientiously and 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.

Table 11.14 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?

PLANT DETAILS (Location identifying number, etc.)		
WORK TO BE DONE		
WITHDRAWAL FROM SERVICE	The above plant has been removed from service and persons under my supervision have been informed <div> <div>Signed</div> <div>Date</div> <div>Time</div> </div>	
ISOLATION	The above plant has been isolated from all sources of ingress of dangerous fumes, etc. <div>Signed</div> The above has been isolated from all sources of electrical and mechanical power <div>Signed</div> The above plant has been isolated from all sources of heat <div> <div>Signed</div> <div>Date</div> <div>Time</div> </div>	
CLEANING AND PURGING	The above plant has been freed of dangerous materials <div> <div>Material(s):</div> <div>Method(s):</div> <div> <div>Signed</div> <div>Date</div> <div>Time</div> </div> </div>	
TESTING	<div> <div>Contaminants tested</div> <div>Results</div> </div> <div> <div>Signed</div> <div>Date</div> <div>Time</div> </div>	
I CERTIFY THAT I HAVE PERSONALLY EXAMINED THE PLANT DETAILED ABOVE AND SATISFIED MYSELF THAT THE ABOVE PARTICULARS ARE CORRECT (1) THE PLANT IS SAFE FOR ENTRY WITHOUT BREATHING APPARATUS (2) APPROVED BREATHING APPARATUS MUST BE WORN Other precautions necessary: Time of expiry of certificate: Delete (1) or (2)		
		<div> <div>Signed</div> <div>Date</div> <div>Time</div> </div>

ACCEPTANCE OF CERTIFICATE	<p>I have read and understood this certificate and will undertake to work in accordance with the conditions in it</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>
COMPLETION OF WORK	<p>The work has been completed and all persons under my supervision, materials and equipment withdrawn</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>
REQUEST FOR EXTENSION	<p>The work has not been completed and permission to continue is requested</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>
EXTENSION	<p>I have re-examined the plant detailed above and confirm that the certificate may be extended to expire at:</p> <p>Further precautions:</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>
THE PERMIT TO WORK	<p>IS NOW CANCELLED. A NEW PERMIT WILL BE REQUIRED IF WORK IS TO CONTINUE</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>
RETURN TO SERVICE	<p>I accept the above plant back into service</p> <p style="text-align: right;">Signed _____ Date _____ Time _____</p>

Figure 11.4 'Permit-to-work' certificate for entry into a confined space. A certificate number is added for identification, authenticity checking etc.

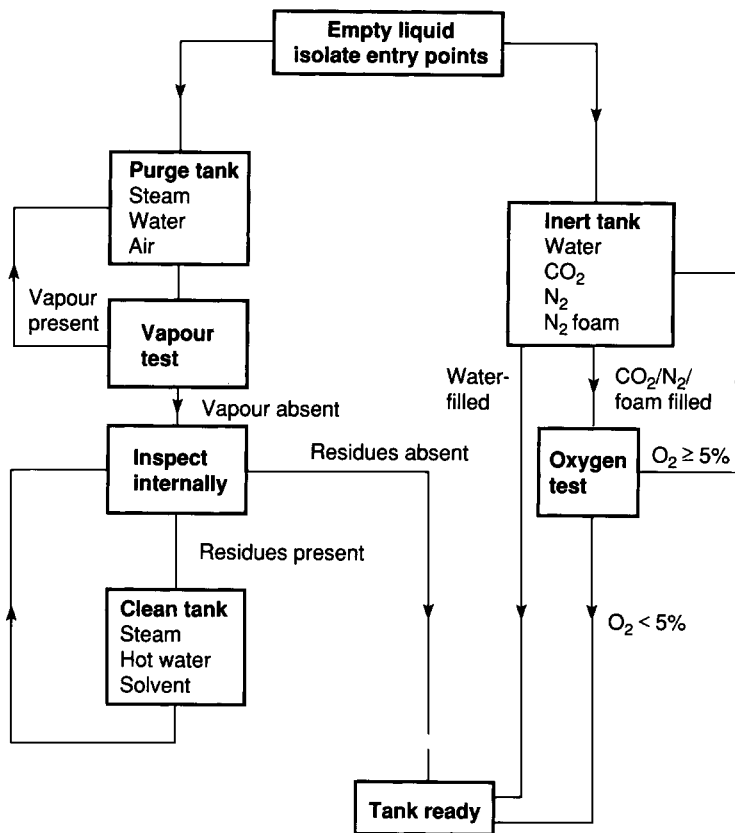


Figure 11.5 Procedure for 'hot work' on equipment that contains, or has contained, a flammable chemical (general summary only: reference should be made to detailed procedures)

Figure 11.6 (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.

**CERTIFICATE OF CONDITIONS AND RESPONSIBILITY OTHER
THAN FOR ENTRY INTO VESSELS OR CONFINED SPACES**

Part 1

WORKS		Certificate No.	
DEPARTMENT		Date of issue	Date 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, motive power, heat and electricity. Details of isolation:			
(2) The above item of plant is not isolated from every (dangerous) source of steam, gas, fume, liquid, motive power, heat and electricity. These special precautions must be taken in addition to (3) and (4) below.			
(3) Naked Flame or Other Source of Ignition	Not Permissible	Permissible: Type:	
(4) Other hazards which may be encountered		Precautions	
Hand Over Issuing Dept Date (Signature) Time Receiving Dept. (Signature)		Hand Back Issuing Dept Date (Signature) Time Receiving Dept. (Signature)	

**AUTHORIZATION TO WORK
OTHER THAN IN VESSELS OR CONFINED SPACES**

Part 2

WORKS		Authorization No.	
DEPARTMENT		Date of issue	Date 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 Source of Ignition	Not Permissible	Permissible Type:	
(4) Precautions to be taken in addition to (2) and (3) above			
Work may start		Date	
(Signature)		Time	
Work completed		Date	
(Signature)		Time	

Pressure systems

The safety of pressure systems in Great Britain is controlled by the Pressure System and Transportable Gas Containers Regulations 1989. These probably apply if

- (a) The plant contains relevant fluid (e.g. compressed air or liquefied gas) 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

Emergency planning is necessary to cover a wide range of eventualities.

Minor emergencies

- Personal injuries (refer to Table 11.17 for chemicals).
- Small fires (refer to Table 5.13).
- Overpressures.
- Spillages etc.
- Process 'excursions', e.g. temperature, pressure.
- Equipment failure.
- Disruption of essential services or computer networks.

Major emergencies

- Fire.
- Explosion.
- Toxic releases.
- Flammables release (unignited).
- Large spillage.
- Pollution episode, on or off site.
- Persons 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

- (a) safeguards personnel;
- (b) minimizes damage to plant and equipment,
- (c) prevents escalation *and*
- (d) 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.

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.

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 required, 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'.

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.

Effective management of an emergency depends upon pre-planning, including:

- 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.
- Provision of action lists, list of emergency contacts, 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 and external 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

For UK sites subject to the CIMAH Regulations (Chapter 1), persons within an area defined by the HSE must be given the following information as a minimum:

- The fact that the hazardous installation is notifiable and has been notified to HSE.
- A description of operations on site and of the hazards and risks that might affect the recipient.

- Emergency measures – including appropriate personal behaviour – to take in the event of an incident.

Following preparation of an on-site plan the Local Authority responsible for emergency planning needs to prepare, and keep up to date, an adequate off-site emergency plan. They will require certain minimum information for this purpose from the occupier, the HSE and others as appropriate. For example, for a site storing LPG with road and rail facilities the information would cover:

- Brief site description including operations and an indication of vessel and equipment sizes.
- An account of materials stored and the hazards associated with loss of containment for various levels of release, including
 - flammable vapour cloud dispersal
 - flash fire/pool fire
 - jet flames
 - vapour cloud explosion
 - BLEVE.
- A quantitative review of the effects of thermal radiation, flash fires, and blast over-pressure on people and buildings surrounding the site.
- A quantitative estimate of hazard distances for a variety of events, e.g. vapour dispersion to 50% LEL from pipework releases, up to second degree burns from a fireball.
- An estimate of the likelihood of a range of release scenarios, e.g. flange weep to whole tank events.

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.
- Create slippery conditions (e.g. detergents, oils).
- Contaminate other materials/processes.

Table 11.15 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 11.16 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)
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

- 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 296), 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 hazardous spillages will be dictated by circumstances (e.g. for mercury see page 66). Actions include:

- Assess the risk (e.g. identify the chemical and its hazardous properties, note the scale and prevailing circumstances etc); 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 11.15. Treatment may require some combination of the measures given in Table 11.16.

Emergencies involving spillages during transport are mentioned in Chapter 12.

First aid

In Great Britain the Health and Safety (First Aid) Regulations 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	Give mouth-to-mouth/respiration
	has no pulse	Start cardiac compressions
	is bleeding	Stop bleeding
	is unconscious	Place in the recovery position
	feels faint	Lie him or her down
	has broken bones	Immobilize
	has open wounds	Cover
	has thermal or chemical burns	Immerse or flood copiously with cold water for ≥ 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.

Table 11.17 Standard first aid treatments for chemical exposure

Splashes on the skin	<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>
Splashes in the eye	<p>Flood the eye thoroughly with large quantities of gently running water, from a tap or from eyewash bottle, and continue for ≥ 10 min</p> <p>Ensure that the water bathes the eyeball by gently prising open the eyelids and keeping them apart until treatment is completed</p> <p>All eye injuries from chemicals require medical advice – arrange transport to hospital</p> <p>Information to accompany the casualty:</p> <p>Chemical involved</p> <p>Details of treatment already given</p>
Inhalation of gas	<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>
Ingestion of poisonous chemical	<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>

Burns/scalds

Burns may arise from fire, hot objects/surfaces, very cold objects, electricity or friction. Scalds may arise from steam, hot water, hot vapour or hot 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. 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.

Chemical splashes

Refer to Table 11.17.

Poisoning by ingestion

Refer to Table 11.17.

All cases of ingestion should be referred to a doctor and/or hospital without delay.

Poisoning by inhalation

Refer to Table 11.17.

Antidotes

Effective antidotes for use in an emergency are not common. Examples include:

- *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.

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 indeed even a legal requirement. If it is to be effective, its selection, correct use and condition are of paramount importance.

Respiratory protection

Recommendations for the selection, use and maintenance of respiratory protective equipment are provided in the UK by BS 4275 1974. The two basic principles are:

- (a) purification of the air breathed (respirator) *or*
- (b) supply of oxygen from uncontaminated sources (breathing apparatus).

If the oxygen content of the contaminated air is deficient (refer to page 43), 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:

$$\text{NPF} = \frac{\text{Concentration of contaminant in air}}{\text{Concentration of contaminant inside facepiece}}$$

NPFs achievable with different respiratory protection devices are summarized in Table 11.18, subject to correct fitting and maintenance.

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.

Table 11.18 Nominal protection factors of respirators and breathing apparatus

Type	Protection factor ⁽¹⁾
General purpose dust respirators	7–10
Positive pressure, powered dust respirators	20–500
Positive pressure, powered dust hoods and blouses	20–500
High efficiency dust respirators	1000
Cartridge-type gas respirators	20 (gas only)
Canister-type gas respirators	400 (gas only)
Escape respirators	BS in course of preparation
Fresh air hose apparatus without blower	2000
Fresh air hose apparatus with blower	2000
Compressed air line apparatus: demand valve type	2000
Compressed air line apparatus: constant flow type	1000–2000
Self-contained breathing apparatus: closed-circuit type	2000
Self-contained breathing apparatus: open-circuit type	2000
Escape breathing apparatus	BS in course of preparation
Combination self-contained and air-line breathing apparatus	According to use

⁽¹⁾ Based on the test procedures and requirements detailed in relevant British Standards, to which reference should be made.

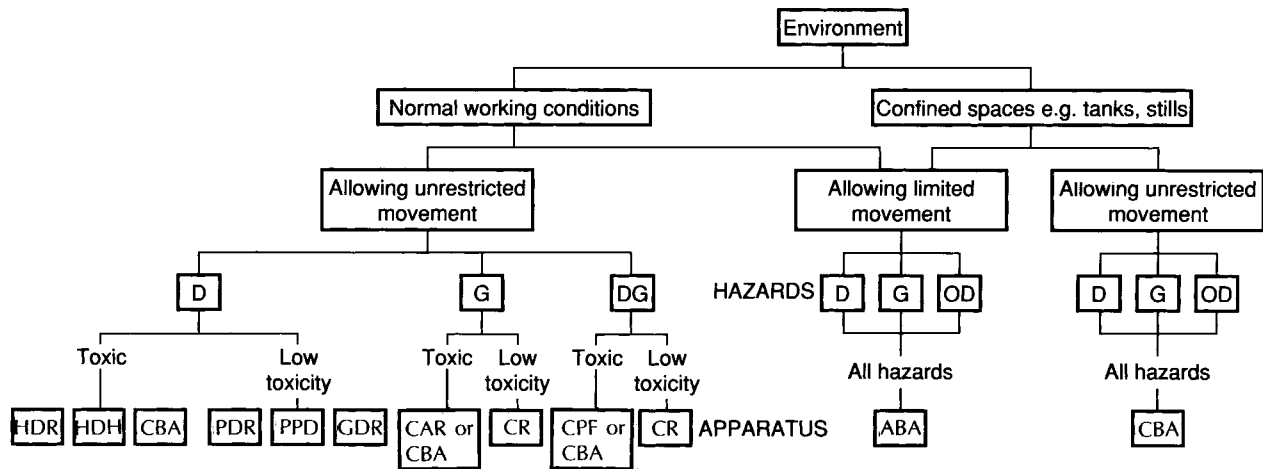


Figure 11.7 Guide to the selection of respiratory protection

hazards

- D Dust
- G Gas
- DG Dust and gas
- OD Oxygen deficiency

Equipment

- ABA Air line breathing apparatus
- CAR Canister respirator
- CBA Self-contained breathing apparatus
- 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

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 11.7. 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.

Table 11.19 Normal range of personal eye protection

Safety spectacles	A variety of styles and colours are available with different side-shields to protect against lateral hazards Attention must be given to both the lens (available toughened/tinted/to personal prescription for wearers requiring corrected vision) and the frame
Cup and wide-vision goggles	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 Tend to be less comfortable than safety glasses and usually cannot be worn over ordinary spectacles Often mist up and as a rule are not fitted with prescription lenses
Face shields	Intended to protect from the forehead to the neck Some are attached to headgear and equipped with a chin-guard to prevent upward splashing of acids/alkalis The transparent screen is commonly made of polycarbonate Heavier special versions are available e.g. for welding

Eye protection

The common-sense approach to the use of eye protection, e.g. under the UK Protection of Eyes Regulations, 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 11.19. In the UK the appropriate standard is BS 2092. (Separate requirements cover protection against UV radiation and laser light.) Fixed shields can be of polycarbonate plastic to guard against splashing and projectiles, or of toughened glass or Perspex against splashing only. Wrap-around of the hazard is required. If the need for access cannot be eliminated personal protection is still necessary.

Table 11.20 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 5240 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

Head protection

Head protection is required against falling objects but also serves against heat, chemical splashes, or entanglement of hair in machinery. The appropriate UK standards are BS 2095 and 2826.

Common-sense guidelines can be deduced from the requirements of 'building operations' and 'works of engineering construction' summarized in Table 11.20. In special situations, e.g. for fire-fighting or protection against toxic chemicals, hoods and suits cover the head and neck and many incorporate head protection.

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.

The suitability and degree of resistance of glove materials are summarized in Table 11.21. 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.

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 11.22.

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 highly toxic chemicals a double locker system is advisable.

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. Minimum recommended standards:

Normal work	One wash-basin per 10 workers
Handling toxic or irritant chemicals	One wash-basin per 5 workers

In some circumstances, where clothing has to be changed, bathing facilities, e.g. showers, are required.

Medical screening

The medical background of workers must be considered for work involving certain chemicals e.g. radioactive substances, sensitizers. (Refer to Chapter 4.)

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.

Table 11.21 Glove material resistance rating (courtesy James North & Sons Ltd)

Chemical	Glove material				
	Natural rubber	Neoprene	Nitrile	Normal PVC	High grade PVC
Organic acids					
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
Inorganic acids					
Arsenic acid	G	G	G	E	E
Carbonic acid	G	G	G	E	E
Chromic acid (up to 50%)	G	F	F	E ⁽¹⁾	G
Fluorosilicic acid	G	G	G	E	G
Hydrochloric acid (up to 40%)	G	G	G	E	G
Hydrofluoric acid	G	G	G	E ⁽¹⁾	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 ⁽¹⁾	F ⁽¹⁾
Perchloric acid	F	G	F	E ⁽¹⁾	G
Phosphoric acid	G	G	G	E	G
Sulphuric acid (up to 50%)	G	G	F	E ⁽¹⁾	G
Sulphurous acid	G	G	G	E	E
Saturated salt solutions					
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

Table 11.21 Cont'd

Chemical	Natural rubber	Glove material			
		Neoprene	Nitrile	Normal PVC	High grade PVC
Alkalis					
Ammonium hydroxide	E	E	E	E	E
Calcium hydroxide	E	E	E	E	E
Potassium hydroxide	E	G	G	E	E
Sodium hydroxide	E	G	G	E	E
Aliphatic hydrocarbons					
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
Aromatic hydrocarbons⁽²⁾					
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 ⁽¹⁾
Halogenated hydrocarbons⁽²⁾					
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
Esters					
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
Ethers					
Diethyl ether	F	G	E	F	G
Aldehydes					
Acetaldehyde	G	E	E	E	E
Benzaldehyde	F	F	E	G	E
Formaldehyde	G	E	E	E	E
Ketones					
Acetone	G	G	G	F	G
Diethyl ketone	G	G	G	F	G
Methyl ethyl ketone	G	G	G	F	G

Table 11.21 Cont'd

Chemical	Natural rubber	Glove material			
		Neoprene	Nitrile	Normal PVC	High grade PVC
Alcohols					
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
Amines					
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
Miscellaneous					
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

⁽¹⁾ Resistance not absolute, but the best available.⁽²⁾ 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.

Table 11.22 Properties of protective clothing materials

<i>Material</i>	<i>Advantages</i>	<i>Disadvantages</i>	
Cotton	Lightweight, reasonably hard-wearing, no static generation Resists penetration of direct splashes of corrosive Unaffected by oils	Liable to shrinkage unless treated More flammable than wool Vulnerable to hot splashes	Suitable for under-gloves
Wool	Resists rapid penetration of direct splashes (more effective than cotton) Resists penetration of dust High absorption and porosity absorbs perspiration	Not resistant to hot splashes Takes up water and dirt Difficult to wash	
Artificial fibres (nylon, Terylene)	Hardwearing Terylene has good acid resistance	Not resistant to hot splashes High initial cost Can allow dust to pass through Static electricity can cause rapid soiling	Ceramic coating of fibres can render dust-proof
PVC	Impervious Non-flammable Chemically and biologically resistant Abrasion resistant	Not resistant to hot splashes Causes sweating unless well ventilated	Used alone or impregnated on fabric For gloves armlets, hats, bibs, spats, suits
Paper	Hygienic (disposable) Fairly resistant to chemicals if treated with polythene film	Liable to wetting if not treated with polythene film No strength Flammable Not resistant to hot splashes	Possibly used for disposable underwear or for clothing for visitors Used under headgear (disposable)
Polythene	Hygienic May be disposable Impervious	Low abrasion resistance Not resistant to hot splashes Low melting point could cause adhesion to skin	Suitable for disposable gloves or headgear

Marketing and transportation

Manufacturers, suppliers and importers of chemicals have a legal obligation to ensure that their products are properly packed, labelled and transported, and to provide the user with information on the hazards and precautions for their use. (See Table 12.1 for UK legislation.)

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.

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 container 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 etc.
- Do not throw used aerosol dispensers onto bonfires.
- Do not let young children have access to aerosol dispensers, full or empty.

It is the responsibility of the supplier to draw these precautions to the attention of the user in the best way practicable.

Table 12.1 Legislation affecting the classification, packaging, labelling and carriage of dangerous substances in Great Britain (including their movement in harbours and harbour areas)

The Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981 ('RTR')	Control the carriage of dangerous substances in all road tankers and in tank containers with a capacity of 3 m ³ or more. They apply to all substances which exhibit any of the dangerous properties detailed in Schedule 1 to the regulations, from the commencement of loading until the tank has been emptied and cleaned or purged, so that any residual substance or its vapour is not sufficient to create a risk to health and safety.
The Classification, Packaging and Labelling of Dangerous Substances Regulations 1984 ('CPLR')¹	Lay down a comprehensive system for the classification, packaging and labelling of dangerous substances for the separate purposes of informing consumers of potential dangers and reducing the hazard when they are carried on the road. Dangerous substances have to be carried in suitable containers which will not leak under normal handling: these containers must also carry the appropriate warning labels. The regulations apply to all substances which exhibit any of the dangerous properties detailed in Schedules 1 and 2.
The Road Traffic (Carriage of Dangerous Substances in Packages etc.) Regulations 1986 ('PGR')	Complement CPLR and apply to the carriage of certain dangerous substances in packages or in bulk, other than in a road tanker or tank container. The dangerous substances are: all toxic gases, all flammable gases, asbestos, most hazardous wastes, those substances listed as dangerous for conveyance in the CPL Approved List which have been allocated to Packing Groups I and II and all other substances with similar properties but not those gases classified as 'non-flammable compressed gas' (such as oxygen and nitrogen), or any substances, such as those classified as 'Harmful', which are allocated to Packing Group III.
The Road Traffic (Carriage of Explosives) Regulations 1989 ('CER')	Impose requirements with respect to the safety and security of explosives carried by road. Explosives include explosive articles or explosive substances which have been assigned on classification to Class 1 (or are classified) in accordance with the Classification and Labelling of Explosives Regulations 1983.
The Ionizing Radiations Regulations 1985 ('IRR 85')	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.
The Radioactive Substances (Carriage by Road) (Great Britain) Regulations 1974 ('CBR')	Subject to the Radioactive Substances Act 1984 and enforced by the Department of Transport. They impose requirements concerning the packaging, labelling and carriage of radioactive materials and the accompanying documentation.

¹ These were replaced in September 1993 by the Chemicals (Hazard Information and Packaging) Regulations. Businesses which already comply with CPLR will not need to change over to CHIP until 1 September 1994, with a further 6 months exemption for some requirements for small packages.

The Dangerous Substances in Harbour Areas Regulations 1987 ('DSHA')

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.

The Classification and Labelling of Explosives Regulations 1983 ('CLER')

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).

Labelling

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. 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 12.2 and 12.3) 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 12.4 and 12.5. Substances not tested should be labelled 'Caution – substance not yet fully tested'. Criteria for risk phrases are provided, e.g. as in Table 12.6 for toxic compounds.



Figure 12.1 Example of label for explosive (Division 1.1, 1.2 or 1.3)

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 12.7), and on compatibility (Table 12.8), 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 12.1 shows the label for Class 1, Division 1.1, 1.2 or 1.3 explosive.










Table 12.2 '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 highly 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. Dangerous 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 12.3 '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
 34. Avoid shock and friction
 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)
 43. In cases of fire, use ... (indicate in the space the precise type of fire-fighting equipment. If water increases the risk, add – Never use water)
 44. If you feel unwell, seek medical advice (show the label where possible)
 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
 52. Not recommended for interior use on large surface areas
 53. Avoid exposure – obtain special instructions before use
 54. Obtain the consent of pollution control authorities before discharging to waste-water treatment plants
 55. Treat using the best available techniques before discharge into drains or the aquatic environment
 56. Do not discharge into drains or the environment, dispose to an authorized waste collection plant
 57. Use appropriate containment to avoid environmental contamination
 58. To be disposed of as hazardous waste
 59. Refer to manufacturer/supplier for information on recovery/recycling
 60. This material and/or its container must be disposed of as hazardous waste
-

Table 12.4 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 $<0^{\circ}\text{C}$ and a boiling point $\leq 35^{\circ}\text{C}$.	Extremely flammable ⁽¹⁾	
A substance which (a) may become hot and finally catch fire in contact with air at ambient temperature without any application of energy; (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; (c) is gaseous and flammable in air at normal pressure; (d) in contact with water or damp air, evolves highly flammable gases in dangerous quantities; or (e) is a liquid having a flash point $<21^{\circ}\text{C}$.	Highly flammable ⁽¹⁾	
A substance which is a liquid having a flash point $\geq 21^{\circ}\text{C}$ and $\leq 55^{\circ}\text{C}$, 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 ⁽¹⁾	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 ⁽²⁾	
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 ⁽²⁾	
A substance which if it is inhaled or ingested or it penetrates the skin, may involve limited health risks.	Harmful ⁽²⁾	
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	

⁽¹⁾ Preparations packed in aerosol dispensers shall be classified as flammable in accordance with Part III of this schedule.

⁽²⁾ 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 12.5 Classification of and hazard warning signs for substances dangerous for conveyance (Schedule 2 Part I)



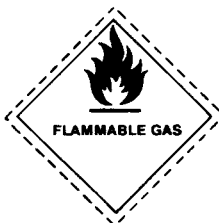



<i>Characteristic properties of the substance</i>	<i>Classification</i>	<i>Hazard warning sign</i>
<p>A substance which</p> <p>(a) has a critical temperature $<50^{\circ}\text{C}$ or which at 50°C has a vapour pressure of more than 3 bar absolute and</p> <p>(b) is conveyed by road at a pressure of more 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 $<50^{\circ}\text{C}$ or which at 50°C 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 $<50^{\circ}\text{C}$ or which at 50°C has a vapour pressure of more than 3 bar absolute and is flammable.</p>	Flammable gas ⁽¹⁾	
<p>A liquid with a flash point $\leq 55^{\circ}\text{C}$ except a liquid which</p> <p>(a) has a flash point $\geq 21^{\circ}\text{C}$ and $\leq 55^{\circ}\text{C}$ and</p> <p>(b) 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.</p>	Flammable liquid ^(1,2)	
<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 12.5 Cont'd



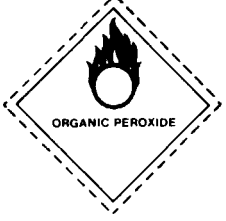




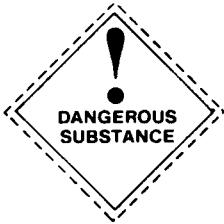
<i>Characteristic properties of the substance</i>	<i>Classification</i>	<i>Hazard warning sign</i>
A substance which in contact with water is liable to become spontaneously combustible or to give off a flammable gas.	Substance which in contact with water emits flammable gas	
A substance other than an 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 (a) an organic peroxide and (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 (a) cause severe damage when in contact with living tissue; (b) materially damage other freight or equipment if leakage occurs.	Corrosive substance	

Table 12.5 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	

⁽¹⁾ 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.

⁽²⁾ Viscous preparations which comply with the conditions in Part III of this schedule shall not be required to be classified as flammable.

Table 12.6 Criteria for the toxicity classification of substances

<i>Category⁽¹⁾</i>	<i>LD₅₀ absorbed orally in rat (mg/kg)</i>	<i>LD₅₀ absorbed percutaneously in rat or rabbit (mg/kg)</i>	<i>LC₅₀ 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

⁽¹⁾ '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 LD₅₀ or LC₅₀ value as the principal basis of classification, the substance should be classified according to the magnitude of these effects.

Table 12.7 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

Table 12.8 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

Information

Suppliers must also provide the customer with more detailed information on the hazards and safety precautions of their products. This is usually in a Material Safety Data Sheet. Relevant information from Table 1.1 should be included and at least cover:

- *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.

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, with the exception of:

- Substances listed in EINECS.
- Medicinal products, narcotics and radioactive substances.
- Pesticides and fertilizers.
- Foodstuffs and feedingstuffs.
- Substances in transit under customs supervision.
- Waste substances.
- Munitions and explosives.
- Certain categories of polymer.

The amount and type of data required in the regulatory submissions depends on the quantity of substance supplied. The tonnage requirements are:

- Limited Announcement <1 tonne per year
- The Base Set >1 tonne per year
- Levels 1 and 2 >10 tonnes per year

Unlike the requirements for >1 tonne, member states have differing test requirements and formats for Limited Announcement (which must be made in each member state in which the substance is supplied). The requirements for the UK are given in Table 12.9. The test requirements for Base Set (Level 0) are shown in Table 12.10: in addition to these data, the submission dossier should contain the test reports plus chemical specification, intended use, immediate and longer term marketing volumes, a declaration concerning any unfavourable effects of the substance, proposed classification and labelling, and recommended precautions for its safe use. The exact test requirements for Level 1 will be subject to the results of Level 0 and exposure patterns to man and the environment.

Table 12.9 Guidance for Limited Announcements (UK)

<i>Category</i>	<i>Quantity</i>	<i>For supply to:</i>	<i>Tests</i>
I	≤1 kg p.a.	Public (including as part of a formulation)	Acute toxicity (oral, dermal or inhalation as appropriate to expected use) Skin irritation
II	1–100 kg p.a.	Public (including as part of a formulation)	As Category I + Ames test
III	100 kg–1 tonne p.a.	Public (including as part of a formulation)	As Category II + eye irritation (unless skin irritation test positive) Skin sensitization
IV	1 tonne p.a.	Within own factory or to skilled persons	As Category III
V	>1 tonne for ≤1 year only (for 'commercial development')	Limited number of registered industrial users	As Category III

Note

Some additional information on the ecotoxicity of the substance may be desirable for Category V and, if harmful amounts may reach the environment, for Categories III and IV.

Table 12.10 Base Set tests

Physicochemical properties	Melting point Boiling point Relative density Vapour pressure Surface tension Water solubility Fat solubility Partition coefficient Flash point Flammability Explosivity Autoflammability Oxidizing properties
Toxicological properties	Acute toxicity (by two routes of admission) Skin irritation Eye irritation Skin sensitization 28 days subacute toxicity Ames test <i>In vitro</i> metaphase analysis (or mouse micronucleus test)
Ecotoxological properties	Acute toxicity to fish Acute toxicity to <i>Daphnia</i> Biodegradability Hydrolysis (abiotic degradability)

Table 12.11 Level 1 tests

Toxicological	Fertility study (one generation) Embryotoxicity (one species) Subchronic/chronic toxicity (one species) Additional mutagenicity
Ecotoxological	Algal growth inhibition 21 day <i>Daphnia</i> toxicity Prolonged toxicity to fish Bioaccumulation in fish Prolonged biodegradation Effect on higher plants Effect on earthworms

Table 12.12 Level 2 tests

Toxicological	Chronic toxicity Carcinogenicity Fertility study (multi-generation) Embryotoxicity (non-rodent) Acute/subacute toxicity in 2nd species Toxicokinetics
Ecotoxicological	Prolonged fish toxicity (including reproduction) Avian acute/subacute toxicity Accumulation, degradation and mobility tests

Examples of Level 1 tests which *may* be required at 10 tonnes per year (or 50 tonnes total) and *will* be required at 100 tonnes per year (or 500 tonnes total) are given in Table 12.11. Level 2 studies which will be required at 1000 tonnes per year (or 5000 tonnes total), unless the supplier can justify their exclusion to the Competent Authorities, are listed in Table 12.10. Until safe data are available the substance should be labelled 'Caution – substance not yet fully tested'.

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.

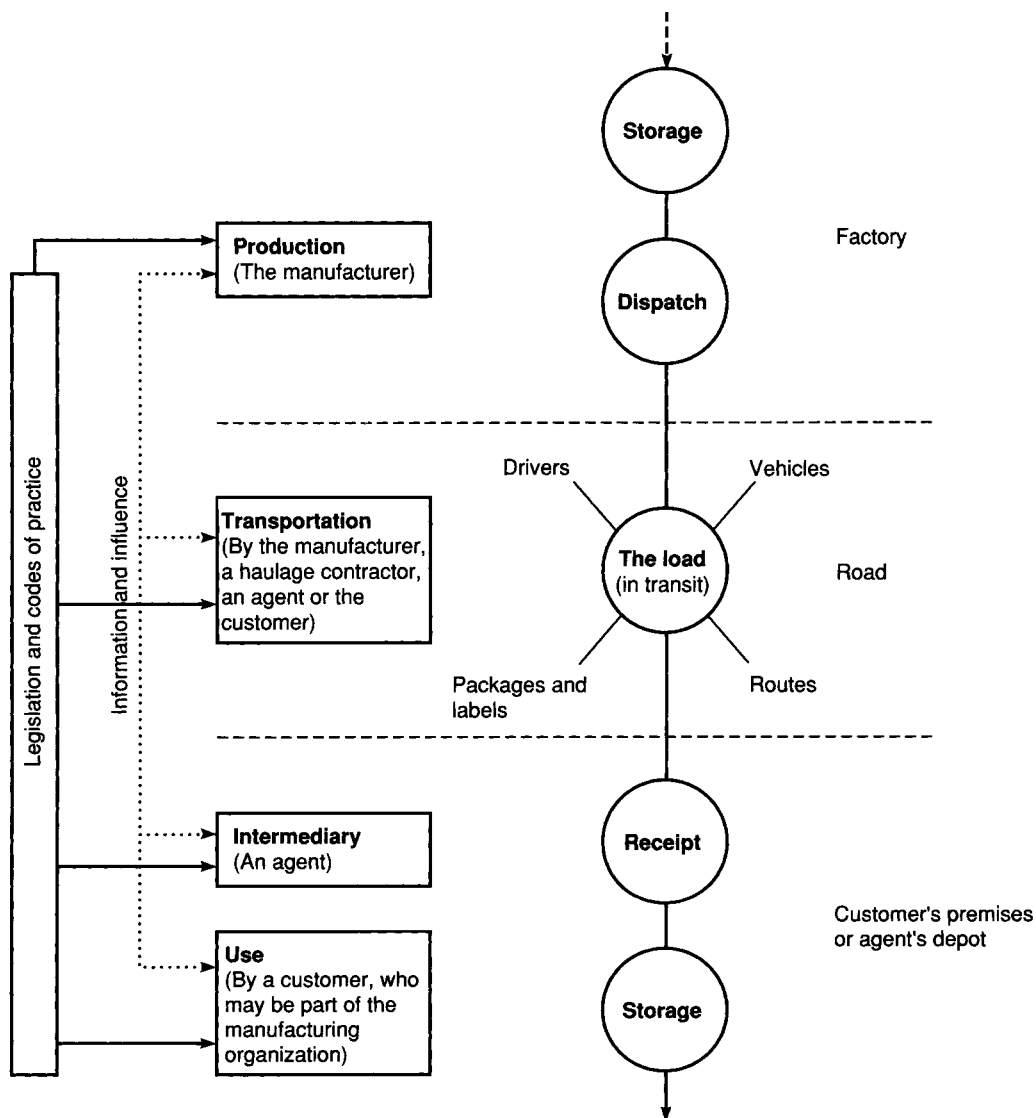


Figure 12.2 Responsibilities for safe transport of chemicals by road

Laboratories wishing to claim GLP compliance are normally registered with Competent Authorities who issue statements of compliance following successful periodic inspections of the premises.

Transportation

Responsibility for the safe transportation of chemicals rests with the chemical producers and their workforce, any haulier used and, to some extent, the customer (e.g. during off-loading), as summarized in Figure 12.2. Effective communication is crucial between all relevant parties. 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 m³ is controlled by the Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981. 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 12.4.

Conveyance includes loading, transportation, unloading, cleaning and purging. A checklist of duties (excluding duties in relation to the unloading of petroleum spirit under Schedule 4) arising where appropriate under these regulations is given in Table 12.13. The regulations also provide instruction on the form of hazard warning labels (Figure 12.3). In the event of an emergency, drivers should normally carry out the actions listed in Table 12.14.

In addition to local legislation and guidance, the transportation of chemicals by road, rail, sea and air 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

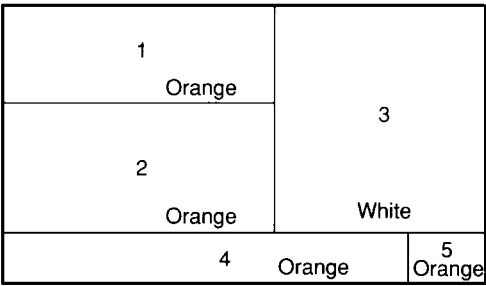


Figure 12.3 *Hazard warning panels and labels*
Space 1 **Emergency action codes** specified for that substance in Column 3 of Part 1 of the approved list
Space 2 **Substance identification number and name** as specified for that substance in Part 1 of the approved list
Space 3 **Hazard warning sign for 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

Regulations concerning the Carriage of Dangerous Goods by Rail, and the International Air Transport Association Restricted Articles Regulations. Thus IATA have banned the transport by air of those compounds listed in Table 12.15; Table 12.16 lists dangerous goods forbidden for transport by air.

Table 12.13 Duties under the Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981

Operator of a road tanker	<ol style="list-style-type: none"> 1. Obtain sufficient information about the substance from the consignor to be able to comply with the regulations and to be aware of the risks involved. 2. Determine whether it is a 'dangerous' substance as defined. If so, classify it from the Approved List or from Schedule 1. 3. Check that the substance can lawfully be conveyed. 4. Check whether the regulations apply to the conveyance. 5. Ascertain that the tanker is properly designed – of adequate strength, of good construction from sound and suitable material – suitable for the purpose and will prevent escape of the contents (this does not exclude the fitting of a pressure relief valve but it must be suitable and be positioned/installed to minimize the risk if it operates). For petroleum spirit, a petroleum mixture or carbon disulphide, check the road tanker for compliance with Schedule 2 'Construction of Road Tankers'. 6. Check that there is a suitable written scheme for initial examination and testing, periodic examination and testing of the carrying tank. 7. Check that there is a certificate for the carrying tank in which a competent person has certified it as suitable for the purpose for which it is to be used. These purposes should be specified in the certificate. 8. Ensure that a current report, signed by a competent person, gives details of examinations and tests on the tank, and the interval before which further examinations and tests must be performed. This report should confirm that the tank is suitable for the purposes stated in the certificate or otherwise define its suitability. 9. Ensure that all precautions for preventing fire or explosion are taken throughout the conveyance. 10. Ensure that the tank is not overfilled. 11. Check that the road tanker is fitted with hazard warning labels and compartment labels. 12. Ensure that the driver has received adequate instruction and training to understand the potential dangers, in emergency action and in his duties under the regulations. 13. Ensure that the driver is provided with written information on the substance conveyed as to its identity, the potential dangers and emergency action. 14. Ensure that hazard warning panels/compartment labels are removed/covered when any/all of the substances have been unloaded and the tank/compartment has been cleaned or purged – such that the dangerous substance remaining is insufficient to create a risk. 15. Ensure that hazard warning panels/compartment labels are displayed at all times as required by the regulations and that they are kept clean and free from obstruction.
Operator of a tank container	<ol style="list-style-type: none"> 16. As 1 above. 17. As 2 above. 18. As 3 above. 19. As 4 above. 20. Ascertain that the tank container is properly designed – of adequate strength, of good construction from sound and suitable material – suitable for the purpose and will prevent escape of the contents. 21. Check that there is a suitable written scheme for initial examination and testing, periodic examination and testing of the tank container. 22. Check that there is a certificate for the tank container in which a competent person has certified it as suitable for the purpose for which it is to be used. These purposes should be specified in the certificate. 23. Ensure that a current report, signed by a competent person, gives details of examinations and tests on the tank container, and the interval before which further examinations and tests must be performed. The report should state that the tank container is suitable for the purposes stated in the certificate or otherwise define its suitability.

Table 12.13 Cont'd

	24. Ensure that the tank container is not overfilled.
	25. Check that the tank container is fitted with hazard warning labels and compartment labels.
Operator of a vehicle conveying a tank container	26. As 12 above.
	27. As 13 above.
	28. As 9 above.
	29. As 14 above.
	30. As 15 above.
Driver	31. Ensure that written information on the substance conveyed – from the vehicle operator – is kept in the cab and is available at all times.
	32. Ensure that this information relates solely to the substance conveyed.
	33. As 9 above.
	34. Ensure that if conveying a dangerous substance with an emergency action code ending with 'E' (subject to certain exceptions) the vehicle when not being driven is either parked in a safe place or is supervised by himself or some other competent person >18 years.
	35. As 14 above.
	36. As 15 above.
Consignor, or other person acting on his behalf	37. Ensure that the information given to the operator concerning substance(s) to be conveyed is accurate and sufficient.
	38. If engaged in the conveyance of the substance (e.g. in loading the tank), ensure that all precautions for preventing fire or explosion are taken throughout the conveyance.
All other persons engaged in the conveyance	39. As 9 above.

Table 12.14 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

Table 12.15 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 triozonide
Benzoxidiazoles (dry)
Benzoyl azide
Biphenyl triozonide
Boron tribromide
Bromine azide
Bromine solutions
4-Bromo-1,2-dinitrobenzene
Bromosilane
1,2,4-Butanetriol trinitrate
tert-Butoxycarbonyl azide
<i>n</i> -Butyl chloroformate
tert-Butyl hydroperoxide, >90% with water
<i>n</i> -Butyl isocyanate
terty-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
Copper amine azide
Copper tetramine nitrate
Crotonaldehyde, stabilized
Cyanogen bromide

Table 12.15 Cont'd

Cyanuric triazide
Cyclohexyl isocyanate
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 >9% by weight
<i>p</i> -Diazidobenzene
1,2-Diazidoethane
1,1'-Diazoaminonaphthalene
Diazoaminotetrazole (dry)
Diazodinitrophenol (dry)
Diazodiphenylmethane
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
<i>N,N'</i> -Dichlorazodicarbonamidine (salts of), (dry)
Dichloroethyl sulphide
Dichlorovinylchloroarsine
2,2-Di-(4,4-di-tert-butylperoxycyclohexyl) propane, more >42% with inert solid
Di-2,4-dichlorobenzoyl peroxide, >75% with water
Diethanol nitrosamine dinitrate (dry)
Diethyleneglycol dinitrate
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
Diketene, inhibited
Dimethylhexane dihydroperoxide, >82% with water
Dimethylhydrazine
Dinitroanilines
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)
Di-(1-naphthoyl) peroxide
Dipropionyl peroxide, >28% in solution
Ethanol amine dinitrate
Ethyl chlorothioformate
Ethylene chlorohydrin

Table 12.15 Cont'd

Ethylene diamine diperchlorate
Ethylene dibromide
Ethylene glycol dinitrate
Ethyl hydroperoxide
Ethyl nitrate
Ethyl perchlorate
Fulminate of mercury (dry)
Fulminating gold
Fulminating mercury
Fulminating platinum
Fulminating silver
Fulminic acid
Furan
Galactsan trinitrate
Glycerol-1,3-dinitrate
Glycerol gluconate trinitrate
Glycerol lactate trinitrate
Guanyl nitrosaminoguanylidene hydrazine (dry)
Guanyl nitrosaminoguanyltetrazene
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
Hydrazine azide
Hydrazine chlorate
Hydrazine dicarbonic acid diazide
Hydrazine perchlorate
Hydrazine selenate
Hydrogen cyanide, unstabilized
Hydroxyl amine iodide
Hyponitrous acid
Inositol hexanitrate (dry)
Inulin trinitrate (dry)
Iodine azide (dry)
Iodoxy compounds (dry)
Iridium nitratopentamine iridium nitrate
Isobutyl isocyanate
Isopropyl chloroformate
Isopropylcumyl hydroperoxide, >72% in solution
Isopropyl isocyanate
Isothiocyanic acid
Lead azide (dry)
Lead nitroresorcinatate (dry)
Lead picrate (dry)
Lead styphnate (dry)
Magnesium dross, wet or hot
Mannitan tetranitrate
Mannitol hexanitrate (dry)
Mercurous azide
Mercury acetylde
Mercury iodide aquabasic ammonobasic (Iodide of Millon's base)
Mercury nitride

Table 12.15 Cont'd

Methazoic acid
 Methoxymethyl isocyanate
 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 iodide
 Methyl isothiocyanate
 Methyl nitramine (dry) salts of
 Methyl nitrate
 Methyl nitrite
 Methyl orthosilicate
 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
 tert-Octyl mercaptan

 Pentaerythrite tetranitrate (dry)
 Pentanitroaniline (dry)
 Perchloric acid >72% strength
 Perchloromethylmercaptan
 Peroxyacetic acid, >43% and with >6% hydrogen peroxide
m-Phenylene diaminediperchlorate (dry)
 Phenyl isocyanate
 Phenyl mercaptan
 Phosphorus (white or red) and a chlorate, mixtures of
 Phosphorus oxychloride
 Phosphorus trichloride
 Potassium carbonyl
n-Propyl chloroformate
n-Propyl isocyanate
 Pyridine perchlorate

 Quebrachitol pentanitrite

Table 12.15 Cont'd

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 octanitrate (dry)
Sulphur chlorides
Sulphuric acid, fuming
Sulphur trioxide, inhibited
2-Sulphuryl chloride
Tetraazido benzene quinone
Tetraethylammonium perchlorate (dry)
Tetramethylene diperoxide dicarbamide
Tetranitro diglycerin
2,3,4,6-Tetranitrophenol
2,3,4,6-Tetranitrophenyl methyl nitramine
Thionyl chloride
Thiophosgene
Titanium tetrachloride
Trimethylacetyl chloride

Table 12.16 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.
Radioactive liquids which are pyrophoric.
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.

Pollution and waste disposal

Examples of industrial chemical waste are given in Table 13.1. Common industrial sources of pollution are given in Table 13.2. Since waste can result in pollution, the two terms are often used synonymously. Wastes can be in the form of solid, liquid or gas, or any combination, e.g. solid waste comprises liquid slurries, sludges, thixotropic solids and solids of varying particle sizes. Typical examples are given in Table 13.3.

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 13.4).
- 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.

Air pollution

Important atmospheric pollutants comprise smoke, dust, grit, fumes and gases. Types of emission are shown in Table 13.5.

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 also be associated with the storage or processing of volatile materials or 'accidents' which occur in handling and transportation. In Table 13.5 emissions are classified as 'persistent' or 'irregular', and according to the height of the discharge. Effects of major pollutants are summarized in Table 13.6.

In considering a limit on concentration of a pollutant at ground level to ensure that there is no danger to health of local residents, it is essential to recognize the important difference from occupational exposure (Table 13.7). Hygiene standards were developed to protect workers from exposure to airborne chemicals during their 8 hr work day, 5 days a week; however, these standards are sometimes used to assess air quality for the local community. To take account of the differences outlined in Table 13.7 a rule of thumb, $1/40 \times$ the hygiene standard, is often employed. 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.

Table 13.1 Types of waste and forms of pollutant

<i>Source</i>	<i>Type of waste</i>	<i>Form of pollutant⁽¹⁾</i>
Agriculture, horticulture	BOD waste (high and low)	L S A
	Disinfectant	A
	Pesticides, herbicides (see below)	PA
	Fertilizers, see Inorganic chemicals	A
Cement, bricks, lime	Chromium	L
	Dust	S
	Fluorides	G
	Sulphur dioxide	G
Coal distillation, coal tar, coke ovens	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
Construction, building, demolition	Combustion products	G P
	Dust	S P
	Metals	S
	Rubble	S
	Timber	S
Electricity generation	Clinker	S
	Combustion products	G
	Cooling water	L
	Pulverized fuel ash	S P
	Sulphur dioxide	G
Fibres, textiles	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	LA
	Wax	P A
Food processing		
Animal	Abattoir waste	L S P A
	BOD waste (high and low)	A
	Disinfectants	A
	Grease	S A
	Oil	L A

Table 13.1 Cont'd

Source	Type of waste	Form of pollutant ⁽¹⁾
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
	Arsenic	A
Glass and ceramic	Barium	S
	Manganese	S
	Selenium	S
	Calcium sulphate	P A
	Ammonia	G A
Hydrofluoric acid	Oxides of nitrogen	A
Nitric acid	Calcium sulphate	P A
	Hydrofluoric acid	A
Phosphoric acid	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
	Sulphur dioxide	G P
	Chlorinated hydrocarbons	G L
Drycleaning	Hydrocarbon solvents	G L
	Bleaches	A
General	Detergents	A
	Phosphates	A
	Sulphates	A
Metals		
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

Table 13.1 Cont'd

<i>Source</i>	<i>Type of waste</i>	<i>Form of pollutant⁽¹⁾</i>
Finishing/surface treatments		
Anodizing	Chromium	A
Degreasing	Chlorinated hydrocarbons	G L
	Detergents	A
	Grease	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	S
Machine shops	Oils	L A
	Oil absorbents	S
	Solvents	L G
	Swarf	S
	Synthetic coolants	L S A
Pickling	Acids	A
	Ferrous chloride	A
	Ferrous sulphate	A
	Hydrochloric acid	A
	Hydrofluoric acid	A
	Nitric acid	A
	Phosphoric acid	A
	Sulphuric acid	A
Pigments, see Inorganic chemicals		
Processing/engineering	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		
Batteries	Cadmium	S P
	Lead	S P
	Manganese	S
	Mercury	S
	Nickel	S
	Zinc	S
Catalysts	Cobalt	S
	Iron	S

Table 13.1 Cont'd

Source	Type of waste	Form of pollutant ⁽¹⁾
Mining (excluding metals)	Manganese	S
	Mercury	S
	Nickel	S
	Organometallics	L S
	Platinum	S
	Silver	S
	Vanadium	S
Paint	Spoil	S
	Dust	S P
Paper, pulp	Barium	S
	Cadmium	S
	Chromium	S
	Copper	S
	Lead	S
	Manganese	S
	Mercury	L S
	Selenium	S
	Solvents	G L
	Titanium	S
	Bleaches	A
	Chlorine	G A
Pesticides, herbicides	Copper	A
	Fibres	S P A
	Lignin	A
	Mercury	A
	Methanol	A
	Sulphides	A
	Sulphite liquor	A
	Titanium	S P A
	Wax	S P A
	Zinc	P A
	Arsenic	S P A
	Carbamates	S P A
	Chlorinated hydrocarbons	L S P A
Petrochemicals	Copper	A
	Fluoride	G S A
	Lead	A
	Mercury	L A
	Organophosphorus compounds	P A
	Phenol	S A
	Polychlorinated biphenyls (PCB)	A
	Selenium	S
	Detergents	S A
	Phosphates	S A
Dyestuffs	Sulphates	S A
	Aniline	L A
	Chromium	L S P A
	Phenol	A
General	Selenium	L S P A
	Benzene, toluene, xylene	L
	Boric acid	A

Table 13.1 Cont'd

<i>Source</i>	<i>Type of waste</i>	<i>Form of pollutant⁽¹⁾</i>
Miscellaneous	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
	Polychlorinated biphenyls (PCB)	L
Polymers, plastics, resins, rubber and fibres	Tetraethyl lead	G L P
	Acids	A
	Alkali	A
	Asbestos	P S
	Cadmium	L S P A
	Cuprammonium compounds	A
	Detergents	A
	Dyestuffs	A
	Fibres	S P
	Formaldehyde	A
Pharmaceuticals	Hydrocarbons	G L A
	Methanol	L A
	Phenols	L S A
	Phthalates	L A
	Polychlorinated biphenyls (PCB)	L A
	Solvents	L A
	Sulphides	A
	Urea	S A
	Wood flour	S P
	Zinc	A
Refineries	Drug intermediates and residues	L S A
	Solvents	L A
	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
Sewage treatment	Sulphides	G S P
	Sulphur	S P
	Tars	S P
	Purified effluent	L
	Sewage sludge	S A
Tanneries	Arsenic	A
	Chromium	A
	Fibres	S P
	Hair	S P
	Lime	P A
		A

Table 13.1 Cont'd

Source	Type of waste	Form of pollutant ⁽¹⁾
Textiles see Fibres	Sulphides	A
Miscellaneous		
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	L S
	Oil	L
	Paint	L S P
	Phosphates	S P A
	Solvents	L
Nuclear fuel and power	Radioactive substances	
	Radioisotopes	
Photography	Alkali	A
	Cyanide	A
	Mercury	A
	Phenols	A
	Silver	P A
	Thiosulphate	A
Vehicle exhaust	Aromatic hydrocarbons	G
	Lead	S P
	Nitrogen oxides	G
Water treatment	Calcium salts	A P
	Filtered solids	L P A

⁽¹⁾ 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 13.2 Common sources of pollutants

<i>Chemical</i>	<i>Form of pollutant⁽¹⁾</i>	<i>Examples</i>	<i>Industrial source</i>
Acid Mineral	A	Hydrochloric acid Nitric acid Sulphuric acid	Pickling Chemical reagent Byproducts, petrochemicals
Organic	A	Acetic acid	Petrochemicals
Aldehydes	A	Acetaldehyde	Photochemical reaction in smog Petrochemicals
Alkali	P A	Sodium hydroxide Lime	Electroplating Beverages production Photography
Ammonia	G A	—	Vegetable and fruit processing Coal distillation (coke ovens) Nitric acid production Urea and ammonium nitrate works
Aniline and related compounds	L A	—	Dyestuffs production
Aromatic hydrocarbons	G L	Benzene Toluene Xylene	Coal tar distillation Vehicle exhausts Petrochemicals Pesticides Herbicides
Arsenic	G S P A	Arsine Arsenous acid and salts	Pigment and dye Pesticide and herbicide production Metallurgical processing of other metals Glass and ceramics industries Tanneries
Asbestos	S P	Chrysotile Amosite Crocidolite	Building products Insulation and removal operations Fillers in various industries Motor vehicle assembly
Carbon dioxide	G A		Polymers, plastics filler Combustion Fermentation
Carbon monoxide	G		Coke ovens Incomplete combustion Smelting Vehicle exhausts Metal extraction and refining
Chlorinated hydrocarbons			
Chemical	G L	Trichloroethylene 1,1,1-trichloroethane	Degreasing (engineering) Drycleaning Solvents
Pesticidal	L S	D D T BHC Aldrin Dieldrin	Pesticides Wood treatment
Chlorine and chlorides	G S P A		Chlorinated hydrocarbons Chloralkali Paper and pulp processing Petrochemicals Metal extraction and refining

Table 13.2 Cont'd

<i>Chemical</i>	<i>Form of pollutant⁽¹⁾</i>	<i>Examples</i>	<i>Industrial source</i>
Chromium and compounds	S P A	Chromic acid Sodium dichromate	Anodizing Cement Dyes Electroplating Paint Tanneries
Cobalt and compounds	S P A	Cobalt oxide	Catalysts Fibres Paint Paper and pulp processing
Copper and compounds	S P A	Copper sulphate Copper pyrophosphate Cuprammonium compounds	Pickling Electroplating Electrical and electronics Etching Pesticides
Cyanate	A		Coal distillation Oxidation of cyanide
Cyanide	S P A	Sodium cyanide Copper cyanide	Heat treatment of metal Photographic Coal distillation Electroplating Synthetic fibre
Disinfectants			Agriculture and horticulture Abattoirs Food processing
Fluorides	G S P A	Hydrogen fluoride Calcium fluoride	Cement Aluminium
Hydrocarbons, general			Coal distillation Petrochemicals Refineries
Iron and compounds	S P A	Iron oxide Ferrous chloride	Aluminium refining Steelworks Electroplating Pickling Pigments Electronics
Lead and compounds	S P A	Lead oxide Tetraethyl lead (TEL)	Titanium dioxide Batteries Printing Vehicle exhausts Explosives and pyrotechnics Pesticides Paint Refineries
Manganese and compounds			Petrochemicals Catalyst Batteries Glass Paint Pyrotechnics
Meat wastes	S A		Meat processing and preparation Abattoirs Dairies
Mercaptans	G		Tanneries Refineries Coke ovens

Table 13.2 Cont'd

<i>Chemical</i>	<i>Form of pollutant⁽¹⁾</i>	<i>Examples</i>	<i>Industrial source</i>
Mercury			
Organic	S A	Methyl mercury	Herbicides Bacterial activity on inorganic mercury
Inorganic	L S A	Mercurous chloride	Pesticides Electrical and electronic Explosives Batteries Photographic Scientific instruments Chloralkali process Paints Pharmaceuticals Paper and pulp Catalysts Cement Combustion of coal and oil
Methanol	L A		Resins Paper
Nitrates	S P	Potassium nitrate	Metals heat treatment Water treatment
Nitrogen oxides	G	Nitrogen dioxide	Combustion processes and explosives Forge tower silos Electricity generation Nitric acid
Oil and soluble oil	L		Engineering Refineries Petrochemicals
Paraquat	L S		Herbicide
Pesticides (includes acaricides, avicides, bactericides, insecticides, molluskicides, nematocides, piscicides, rodenticides)		Chlorinated hydrocarbons (q.v.) Carbamates (q.v.) Organophosphorus compounds (q.v.)	
Pharmaceuticals	L S P A	Aspirin Penicillin	Pharmaceutical industry
Phenol and related compounds	S P A	Phenol Cresol	Photographic Coal distillation Dyestuffs Petrochemicals Pesticides Refineries Explosives Plastics manufacture Detergents Fertilizers Corrosion protection Matches Boiler blowdown Metal finishing Plasticizer (polymers)
Phosphorus and compounds	S P A	Phosphoric acid	Catalysts Pesticides Plasticizer in paint and polymers
Phthalates	L S P A	Dibutyl phthalate	
Platinum and compounds	S P		
Polychlorinated biphenyls (PCB)	L S A		

Table 13.2 Cont'd

<i>Chemical</i>	<i>Form of pollutant⁽¹⁾</i>	<i>Examples</i>	<i>Industrial source</i>
Silicates	P		Adhesives Lubricants and hydraulic fluids Transformer oils Cement
Sulphur oxides	G	Sulphur dioxide Sulphur trioxide	Metal extraction and refining Coal distillation Combustion of coal and heavy fuel oil
Tar	L		Electricity generation Refineries
Thiocyanate	A		Coal distillation
Tin and compounds	G S P A		Tinplating
Titanium and compounds	S P A	Titanium dioxide	Paper Paint
Vanadium and compounds	S P	Catalysts	Astronautics
Vegetable waste	L S P A		Natural rubber Starch Breweries Sugar refineries Vegetable and fruit processing and preparation
Wax	S		Animal feed Paper Refineries Fruit preserving
Zinc and compounds	G S P A		Textiles Synthetic fibres Galvanizing Electroplating Paper and pulp

- ⁽¹⁾ 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 13.3 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, some in sea Some used	As fill and in manufacture of bricks, cement and lightweight aggregate
China clay waste, overburden sand, micaceous residue	Quarrying	Mainly tipping and in lagoons Some used	As fine aggregate in concrete, in manufacture of bricks and blocks and as fill
Household refuse	Household	Mainly landfill Some incineration	Some resource and energy recovery

Table 13.3 Cont'd

<i>Type</i>	<i>Origin</i>	<i>Method of disposal</i>	<i>Present uses</i>
Pulverized fuel ash and furnace bottom ash	Waste from power stations burning pulverized coal	Some used Remainder in old workings or artificial lagoons	As fill and in manufacture of cement, concrete blocks, light-weight aggregate, bricks etc.
Blastfurnace slag	Iron smelting	Nearly all used	As roadstone, railway ballast, filter medium, aggregate for concrete, fertilizer and in manufacture of cement
Trade waste	Industry	Mainly landfill Some incineration	Not known
Steel-making slag	Steel making	Some returned to blast-furnaces, remainder dumped or used as fill near steel works, or sold	As roadstone
Furnace clinker	Waste from chain grate power stations	All used	Concrete block making
Incinerator ash	Residue from direct incineration	Most dumped Minor usage	As fill and for covering refuse tips
Byproduct calcium sulphate	Manufacture of phosphoric acid and of hydrofluoric acid	Mainly in sea. Some dumped on land	In manufacture of floor screeds
Waste glass	Waste glass within household refuse	Some used No utilization in household refuse	If segregated, recycled
Slate waste	Mining and quarrying slate	Mainly tipping, some backfilling of old workings Minor usage	Inert filler, granules, expanded slate aggregate and filter medium, road building
Tin mine tailings	Tin mining	Minor utilization. Tailing lagoons and discharge into sea	Aggregate for concrete
Fluorspar mine tailings	Fluorspar mining	Minor utilization Tailing lagoons	Aggregate for roadmaking and concrete
Red mud	Production of alumina	Minor utilization, rest in lagoons	Pigment in paints and plastics
Copper slag	Smelting	Complete utilization	Grit blasting
Tin slag	Smelting	Major utilization Some in tips	Grit blasting and road building
Zinc-lead slags	Smelting of zinc and lead	Stockpiled and used locally	Bulk fill and some in pavement asphalt
Quarry wastes	Quarrying	Some utilization Remainder tipped	Roadmaking, brickmaking

Table 13.4 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 Ferrous metals Copper Aluminium Building materials (limestone, marble, slate, mortar)	Corrosion Corrosion to copper sulphate (green) Corrosion to aluminium sulphate (white) Leaching, weakening

Table 13.4 Cont'd

<i>Pollutant</i>	<i>Primary materials attacked</i>	<i>Typical effect</i>
Hydrogen sulphide	Leather	Embrittlement, disintegration
	Paper	Embrittlement
	Textiles (natural/synthetic)	Reduced tensile strength, deterioration
	Metals	
	Silver	Tarnish
Ozone	Copper	Tarnish
	Paint	Leaded paint blackened by formation of lead sulphide
	Rubber and elastomers	Cracking, weakening
Nitrogen oxides	Textiles (natural/synthetic)	Weakening
	Dyes	Fading
Hydrogen fluoride	Dyes	Fading
Solid particulates (soot, tars)	Glass	Etching, becoming opaque
	Building materials	Soiling
Acid water (pH < 6.5)	Painted surfaces	Soiling
	Textiles	Soiling
Ammonium salts	Cement and concrete	Slow disintegration
		Slow to rapid disintegration
Fats, animal or vegetable oils		If cement is porous, corrosion steel reinforcement may occur
Calcium chloride		May cause slow disintegration
Calcium sulphate (and other sulphates)		May cause steel corrosion if concrete is porous/cracked
Solvents		Disintegrates concrete of inadequate sulphate resistance
Oxalic acid		May cause changes due to penetration
Paraffin		Beneficial: reduces effects of CO ₂ , salt water, dilute acetic acid
Phenol (5% solution)		Slow penetration, not harmful
Caustic alkali		Slow disintegration
		Not harmful <10–15% concentration

Table 13.5 Continuous/intermittent emissions to atmosphere

High level		
Routine	Vents	General ventilation (factory atmosphere)
	Flare stacks	Local extraction (dust, fumes, odour)
	Chimney	Normal flaring
Irregular	Plant maloperation	Process plant
	Flare stack	Dust and fume extraction plant
	Plant failure	Emergency/occasional flaring
Low level		Process plant – emergency venting
		Extraction/collection plant (cyclones, precipitators, filters, scrubbers)
	Process equipment cleaning	
	Materials handling (discharge, conveying, bagging)	
	Waste handling/deposition	
	Plant maloperation (e.g. unauthorized 'venting')	
Irregular	Plant failure – spillages	
	Start-up/shutdown	
	Dismantling/demolition	
	Unauthorized waste incineration (rubbish burning)	

Table 13.6 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 Petroleum refining, metal smelting, paper-making	Vegetation damage Sensory and respiratory irritation Corrosion Discoloration of buildings
Hydrogen sulphide	Various chemical processes Oil wells, refineries Sewage treatment	Odours, toxic Crop damage and yields reduced
Carbon monoxide	Auto 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 Byproduct from manufacture of fertilizer	Adverse health effects Sensory irritants Reduced visibility Crop damage
Ammonia	Waste treatment	Odour Irritant
Fluorides	Aluminium smelting Manufacture of ceramics, fertilizer	Crop damage HF has adverse health effects on cattle fed on contaminated food
Lead	Combustion of leaded petrol Solder, lead-containing paint Lead smelting	Adverse health effects
Mercury	Manufacture of certain chemicals, paper, paint Pesticides Fungicides	Adverse health effects
Volatile hydrocarbons	Motor vehicles Solvent processes Chemical industry	Vegetation damage (especially unsaturated hydrocarbons) Some are irritants Adverse health effects
Particulates	Chemical processes Fuel combustion Construction Incineration processes Motor vehicles	Nuisance Adverse health effects Reduced visibility Deposition on buildings

Water pollution

Table 13.8 identifies common pollutants in aqueous effluents. Of the metals, the most toxic are salts of the heavy metals beryllium, cadmium, chromium, copper, lead, mercury, nickel and zinc.

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 13.9), low pH can result in the leaching of toxic metals from land etc.

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

Table 13.7 Factors in exposure and effects of air pollutants

<i>Exposure</i>	<i>Occupational</i>	<i>Environmental</i>
Population	Adults (16–65) Fit for work (Health possibly monitored)	All population including infants, aged and infirm
Period	Basic working week, e.g. <40 hr/wk, 48 wk/yr plus overtime; therefore intermittent elimination and recovery times	Continual unless area vacated; therefore elimination and recovery depend on irregular periods of low/ zero concentrations
Levels	Possibly measurable fractions of OESs (mg/m ³)	Normally very low: at limits of analytical/instrumental sensitivity (µg/m ³)
Dust, fume, gas, vapour, mist	Generally single pollutants Known origin Hazards probably known Recognized problem Personal protection provided Probably freshly formed/released	Mixture of primary pollutants, from different sources and secondary pollutants Origins may be difficult to prove Hazards not quantified Exposure largely unheeded
Concern	Specific effects, therefore increased costs, accident rate; reduced productivity	Decreased well-being Non-specific respiratory troubles Irritation of eyes, nose and throat Damage to property and vegetation Injury to animals Decrease in 'amenity' Long-term ecological effects

strong sunshine. This chokes the water and results in depletion of light and oxygen content.

There is a vast range of aqueous organic pollutants with a wide toxicity profile. Some, e.g. polychlorinated biphenyls, certain herbicides, fungicides and pesticides, and organo-mercury compounds, are persistent and may bioaccumulate in the food chain. Trace contaminants such as sodium chloride, iron and phenols (especially if chlorinated) may also impart a taste to water. Typical 'consent' levels for industrial discharges are provided in Table 13.10.

Land pollution

Sources of land pollution include direct dumping of domestic and industrial solid waste, 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 13.11: some materials are difficult to dispose of safely on land (Table 13.12).

Table 13.8 Common pollutants of aqueous effluents

<i>Pollutant</i>	<i>Example</i>
Alkali	Sodium hydroxide (caustic soda) Potassium hydroxide (caustic potash) Calcium oxide (lime) Calcium hydroxide Sodium, potassium and calcium carbonates Ammonia (q.v.)
Ammonia	
Biocides	
Biodegradable waste	Sewage Food waste Organic chemicals
Boron, borates, fluoroborates	—
Bromine	—
Chloride	Sodium chloride
Chlorine	Hypochlorites
Chromic acid (hexavalent chromium)	Potassium dichromate
Cyanide	Copper cyanide Nickel cyanide Potassium cyanide Silver cyanide Sodium cyanide Zinc cyanide
Emulsified oil	Suds
Fluoride	—
Flourine	—
Metal salts in alkaline solution	Cuprammonium complex Nickel and cobalt ammonia complex Cyanides (q.v.) Copper pyrophosphates Plumbites Zincates
Metal salts in acid solution	Most metals as acid salts, e.g. chloride nitrate sulphate
Mineral acid	Hydrobromic acid Hydrochloric acid Hydrofluoric acid Nitric acid Sulphuric acid
Miscible/soluble organic materials	Acetone Alcohol Acetic acid
Non-metallic inorganic dissolved compounds	Arsenic Selenium
Oil, grease, wax and immiscible organics	Lubricating oil Animal fat Chlorinated solvents
Organometallic compounds	—
pH	Acids Alkalis
Pharmaceuticals	—
Phenols and related compounds	Phenol Cresol
Phosphate	Detergents
Sewage	—
Sulphate	Calcium sulphate
Sulphite liquor	Sodium sulphite

Suspended particles	—
Total dissolved solids	Carbonate Chloride Nitrate Phosphate Sulphate

Table 13.9 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
5.5	Sensitive insects, phytoplankton and zooplankton die
5.0	Whitefish and grayling die
4.5	Perch and pike die
4.0	Eels and brook trout die Crickets, frogs and northern spring peepers die

Table 13.10 Typical consent conditions for the discharge of industrial effluent to rivers and streams (UK)

	<i>Maximum allowed</i>
Fishing streams	
BOD (5 days at 20°)	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
Non-fishing streams	
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

Table 13.11 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%

Table 13.12 Materials difficult to dispose of safely on land

1 Non-biodegradable hazardous materials Chlorinated hydrocarbons Slowly degradable materials Mineral oils, greases	3 Strongly acid or alkaline materials in quantities which would disturb the neutrality of the landfill Hydrochloric, sulphuric, nitric, phosphoric, chromic, or hydrofluoric acid Sodium hydroxide
2 Poisonous or persistent materials, including heavy metals Phenols Cyanides, including metal-cyanide complexes Drug residues Chromium, cadmium, lead, mercury, nickel, copper, zinc Rodenticide and pesticide residues	4 Non-aqueous liquid wastes where these would dissolve material used in sealing a site

Control of pollution and waste disposal

Techniques for the control of gaseous, liquid and solid pollutants are summarized in Tables 13.13, 13.14 and 13.15 respectively. The overall stages in handling waste are summarized in Figure 13.1: some waste may require pretreatment.

Table 13.16 sets out the major waste disposal methods, and potential hazards from toxic waste deposition are indicated in Table 13.17. The range of precautions required at land tips depends upon the risk, e.g. 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.

As well as providing technical controls, management must consult local legislation and conduct pollution audits.

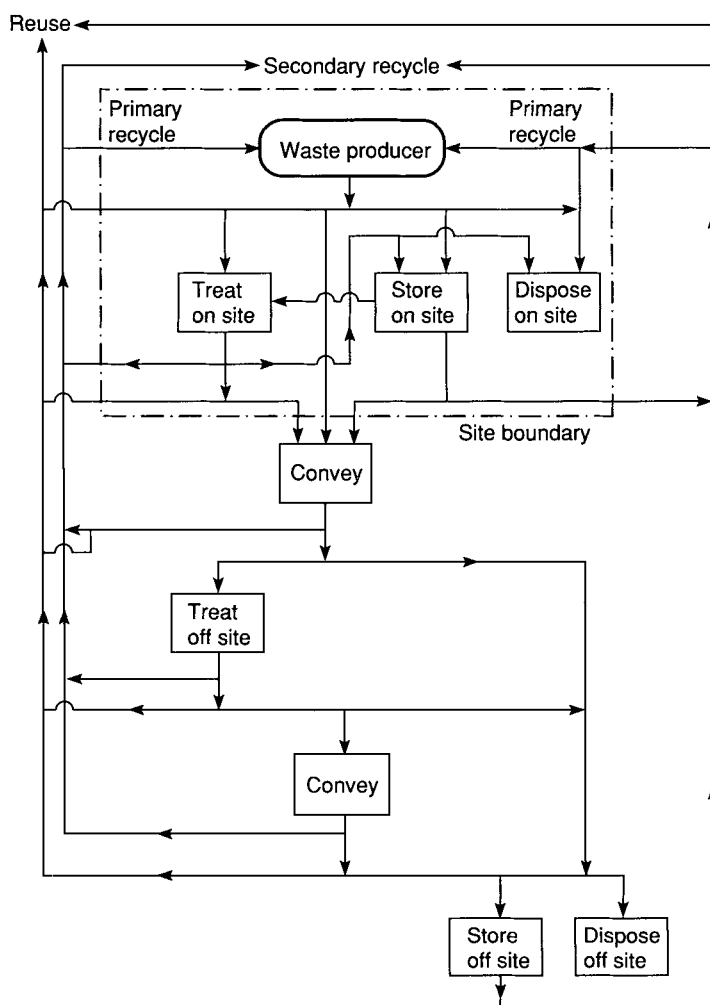


Figure 13.1 Three basic techniques – treatment, storage, conveyance – to effect recycle or disposal of ‘solid’ waste either on or off site

Table 13.13 Treatment methods for gaseous waste

General methods	Alternatives	
Centrifugal techniques	Centrifuge Cyclone	
Coalescence		
Condensation		
Destruction	Chemical reaction Incineration	
Direct recycle		
Dispersion		
Electrostatic precipitation		
Filtration	Needle bonded fabric Reverse jet Reverse pressure Shaker type	
Gravity settlement		
Total enclosure		
Wet scrubbing	Absorption tower Fluidized bed scrubber Impingement scrubber Irrigated target scrubber Pressure spray scrubber Rotary scrubber Self-induced spray scrubber Spray tower Venturi scrubber	
Waste gas treatment system		
Dry methods	Pollutant	Wet methods
Absorption	Gas	Wet scrubbing
Destruction		
Direct recycling		
Dispersion		
Total enclosure		
Destruction	Liquid	Centrifugal techniques Coalescence Destruction Gravity settlement Total enclosure Wet scrubbing
Centrifugal techniques	Solid	Electrostatic precipitation Wet scrubbing
Destruction		
Direct recycling		
Electrostatic precipitation		
Filtration		
Gravity settlement		
Total enclosure		

Table 13.14 Treatment methods for liquid effluent

<i>Treatment method</i>	<i>Example</i>
Chemical	
Cementation	Copper recovery
Chlorination	Cyanide oxidation
Coagulation, <i>see</i> Flocculation	
Demulsification	Soluble oil recovery
Electrolytic processes	Metal 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
Physical	
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	
Biological	
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

Table 13.15 Treatment methods for solid waste

<i>Treatment method</i>	<i>Examples/comments</i>
Chemical	
Calcination	Gypsum
Chlorination	Tin removal
Cooking	Inedible offal
Froth flotation	Coal recovery
	Glass
Hydrolysis	Household refuse
	Vegetable waste
Incineration	Household refuse
Leaching	Gives an aqueous solution for treatment as liquid waste (Table 13.14)
Oxidation	Weathering
Pyrolysis	Household refuse
	Polystyrene
Sintering	Colliery spoil
	Millscale
Physical	
Adhesion	Household refuse
Agglomeration	Pulverized fuel ash
Ballistic separation	Household refuse
Baling	Cans
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 13.14
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
Biological	
Anaerobic digestion	Farm waste
Bacterial leaching	Low-grade copper ore
Composting	Household refuse
Degradation	Plastic
Fermentation	Requires solution or dilute slurry, see Table 13.14

Table 13.16 Major waste disposal methods

Landfill/tipping
Incineration (needs control of gaseous pollutants and solids, see e.g. Table 13.13)
Dumping at sea
Recycling (primary or secondary)
Pyrolysis (to provide useful products)
Sealing in polymer
Long-term storage (radioactive waste)

Table 13.17 Potential hazards from toxic waste deposition

Air pollution	Dust, effluvia, smoke and fume Toxic or flammable gas generation
Land pollution	Gross amenity damage Undermining of site stability Sterilization of surrounding land due to heavy metals pH changes etc. Permanent 'land contamination'
Water pollution	Deposited material or percolate escapes either by surface run-off or by underground movement, threatening streams, rivers, aquifers or even the sea Direct 'poisoning' or eutrophication

Auditing

A typical environmental pollution audit includes:

- 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.
- 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.
- 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).
- Checking for land contamination.

Legislative control

Legislative controls are generally applicable to the various forms of wastes and disposal routes.

The Environmental Protection Act 1990

This act completely reformed arrangements for controlling pollution at national and local levels and created a complete interlocking framework for pollution control. It introduced integrated pollution control (IPC), a new approach with waste minimization at its centre and a commitment to higher environmental standards via the concept of the 'best practical environmental option' (BPEO). The reform of waste disposal is designed to minimize waste and maximize recycling.

Under Part I of the act an IPC system controls emissions to air, land or water for the most polluting industrial and similar processes. IPC is limited to prescribed processes (e.g. chemical, fuel and power, waste disposal, minerals etc.) by prior authorization. Authorization is based on the requirement for owners/controllers to prevent release of prescribed substances or, where this is not practicable, to reduce the release to a minimum. Any residual release must be rendered harmless. To achieve these aims, operators must use the 'best practicable means not entailing excessive cost' (BATNEEC).

This is to be supplemented by extending local authority control of air pollution to cover a second tier of less polluting processes, but incinerators for waste chemicals or waste plastic arising from their manufacture and other waste incinerators, dependent upon size, are subject to both the BATNEEC and BPEO requirements under the IPC regime.

Part II deals with waste disposal, handling and management: the provisions impose duties on producers of waste to ensure its safe disposal, and include stronger licensing powers for local authorities, together with continuing responsibilities for licensees to monitor and maintain sites after closure. 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?
- Checking-up on disposal

Report any suspicions to the Water Research Association
Change carrier/contractor.

Part III re-enacted the law on statutory nuisance with changes to the Public Health Act 1936, controls over offensive trades being transferred to Part I.

Part IV provided new measures to deal with litterers.

Part V contains amendments to the Radioactive Substances Act 1960, Part VI controls the use, import, containment or release of genetically modified organisms to the environment, and Part VII provided for the reorganization of the Nature Conservancy Council and Countryside Commission.

Part VII covers miscellaneous measures including new restrictions over the import, use, supply and storage of injurious substances; new controls over trade in waste; powers to obtain information about potentially harmful substances; public registers of land which may be contaminated; amendments to planning legislation governing the siting and storage of hazardous substances; and increased penalties for polluting controlled waters.

The timetable for the introduction of these measures extends to 1996.

Discharges of trade effluent to surface waters

Discharges of trade effluent, or sewage effluent, to 'controlled waters' (e.g. any inland waters but not sewers, landlocked lakes and reservoirs, any coastal or tidal waters within 3 miles of the territorial limit, underground or ground waters) require a consent from the National River Authority under the Water Act 1989. Discharges through a pipe from land to the sea outside controlled waters, or from a building or plant to land or landlocked waters, are also covered.

Discharges of trade effluent to sewers

Discharge of trade effluent into a sewer requires a consent from the Sewerage Undertaker under a procedure set out in the Public Health (Drainage of Trade Premises) Act 1961, Control of Pollution Act 1974 and Water Act 1989. The Environmental Protection Act 1990 is also applicable to prescribed processes and substances.

Special provisions control specific dangerous substances likely to pass through the system into the natural environment. These 'Red List' substances are defined in the Trade Effluents (Prescribed Processes and Substances) Regulations 1989 and shown in Table 13.18.

Table 13.15 Prescribed substances

Aldrin	Gamma-hexachlorocyclohexane (Lindane)
Atrazine	Hexachlorobenzene
Azinphos-methyl	Hexachlorobutadiene
Carbon tetrachloride	Malathion
Chloroform	Mercury
3-Chlorotoluene	Pentachlorophenol
Chlorprene	Polychlorinated biphenyl
Cadmium	Simazine
DDT	Tenitrothian
1,2-Dichloroethane	Trichlorobenzene
Dichlorvos	Trifluralin
Dieldrin	Triorganotin compounds
Endosulfan	

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>
Base units			
Length	metre	m	—
Mass	kilogramme	kg	—
Time	second	s	—
Electric current	ampere	A	—
Temperature	kelvin	K	—
Luminous intensity	candela	cd	—
Supplementary units			
Plane angle	radian	rad	—
Solid angle	steradian	sr	—
Derived units			
Frequency	hertz	Hz	s ⁻¹
Force	newton	N	kg m/s ²
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 ²
Inductance	henry	H	Wb/A
Luminous flux	lumen	lm	cd sr
Illumination	lux	lx	lm/m ²

Other metric units

<i>Quantity</i>	<i>Unit</i>	<i>Symbol</i>	<i>Equivalent</i>
Length	angstrom	Å	10 ⁻¹⁰ m
	micrometre	μm	10 ⁻⁶ m
Area	are	a	10 ² m ²
Volume	litre	l	10 ⁻³ m ³
Mass	tonne	t	10 ³ kg
Force	dyne	—	10 ⁻⁵ N
Pressure	pascal	Pa	1 N/m ²
	bar	bar	10 ⁵ N/m ²
Energy	erg	—	10 ⁻⁷ J
Viscosity (dynamic)	centipoise	cP	10 ⁻³ Ns/m ²
			(= 1 mPa s)
Viscosity (kinetic)	centistokes	cSt	10 ⁻⁶ m ² /s
Electrical conductivity	siemens	S	1 Ω ⁻¹
Magnetic field strength	oersted	—	10 ³ /4πA/m
Magnetomotive force	gilbert	—	10/4πA
Magnetic flux density	gauss	—	10 ⁻⁴ T
Magnetic flux	maxwell (or line)	—	10 ⁻⁸ Wb
Luminance	nit	nt	1 cd/m ²
	stilb	—	10 ⁴ cd/m ²

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	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Temperature

$^{\circ}\text{C}$	$^{\circ}\text{C} + 273.15 = \text{K}$ $^{\circ}\text{C} \times (1.8) + 32 = ^{\circ}\text{F}$ $^{\circ}\text{C} \times (1.8) + 491.58 = ^{\circ}\text{R}$
$^{\circ}\text{F}$	$^{\circ}\text{F} + 459.48 = ^{\circ}\text{R}$ $(^{\circ}\text{F} - 32) \times 5/9 = ^{\circ}\text{C}$ $(^{\circ}\text{F} - 32) \times 5/9 + 273.15 = \text{K}$
K	$\text{K} - 273.15 = ^{\circ}\text{C}$ $(\text{K} - 273.15) \times 1.8 + 32 = ^{\circ}\text{F}$
$^{\circ}\text{R}$	$^{\circ}\text{R} - 459.48 = ^{\circ}\text{F}$ $^{\circ}\text{R} - 491.58 \times 5/9 = ^{\circ}\text{C}$ $(^{\circ}\text{R} - 491.58) \times 5/9 + 273.15 = \text{K}$

Length

	<i>To obtain:</i>						
	m	cm	mm	μm	\AA	in	ft
<i>Multiply no. of</i>							
m by	1	100	1000	10^6	10^{10}	39.37	3.28
cm by	0.01	1	10	10^4	10^8	0.394	0.0328
mm by	0.001	0.1	1	10^3	10^7	0.0394	0.00328
μ by	10^{-6}	10^{-4}	10^{-3}	1	10^4	3.94×10^{-5}	3.28×10^{-6}
\AA by	10^{-10}	10^{-8}	10^{-7}	10^{-4}	1	3.94×10^{-9}	3.28×10^{-10}
in by	0.0254	2.540	25.40	2.54×10^4	2.54×10^8	1	0.0833
ft by	0.305	30.48	304.8	304 800	3.048×10^9	12	1

1 angstrom (\AA) = 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

1 mil = 0.001 in exactly
= 0.0254 mm

Area

	<i>To obtain:</i> m²	in²	ft²	cm²	mm²
<i>Multiply no. of</i>					
m² by	1	1550	10.76	10 000	10 ⁶
in² by	6.452×10^{-4}	1	6.94×10^{-3}	6.452	645.2
ft² by	0.0929	144	1	929.0	92 903
cm² by	0.0001	0.155	0.001	1	100
mm² by	10 ⁻⁶	0.001 55	0.000 01	0.01	1

$$1 \text{ cm}^2 = 0.155 \text{ in}^2$$

$$1 \text{ m}^2 = 1.196 \text{ yd}^2$$

$$1 \text{ km}^2 = 247.104 \text{ acres}$$

$$= 0.386 \text{ square mile}$$

$$1 \text{ yd}^2 = 0.836 \text{ m}^2$$

$$1 \text{ square mile} = 259.0 \text{ hectares}$$

Mass

	<i>To obtain:</i> g	kg	gr	oz	lb
<i>Multiply no. of</i>					
g by	1	0.001	15.432	0.035 27	0.002 20
kg by	1000	1	15 432	35.27	2.205
gr by	0.0648	6.480×10^{-5}	1	2.286×10^{-3}	1.429×10^{-4}
oz by	28.35	0.028 35	437.5	1	0.0625
lb by	453.59	0.4536	7000	16	1

$$1 \text{ short ton} = 2000 \text{ lb}$$

$$= 0.892 857 \text{ long ton}$$

$$= 907.1846 \text{ kg}$$

$$= 0.907 1846 \text{ t}$$

$$1 \text{ tonne (t)} = 1000 \text{ kg}$$

$$= 2204.623 \text{ lb}$$

$$= 1.102 31 \text{ short tons}$$

$$= 0.984 2107 \text{ long ton}$$

$$1 \text{ long ton} = 2240 \text{ lb}$$

$$= 1.12 \text{ short tons}$$

$$= 1016.047 \text{ kg}$$

$$= 1.016 047 \text{ t}$$

Volume

	<i>To obtain:</i> ft³	Imp gal	litres	cm³	m³
<i>Multiply no. of</i>					
ft³ by	1	6.229	28.32	28 320	0.0283
Imp gal by	0.1605	1	4.546	4546	4.55×10^{-3}
litres by	0.035 31	0.220	1	1000	1×10^{-3}
cm³ by	3.531×10^{-5}	2.20×10^{-4}	0.001	1	10^{-6}
m³ by	35.31	220	1000	10^6	1
<hr/>					
1 cm ³ = 0.061 023 7 in ³ = 1 ml = 0.035 1951 fl oz = 0.033 814 US fl oz		1 ft ³ = 1728 in ³ 1 fl oz = 1.7339 in ³ = 28.413 cm ³ or ml = 0.960 76 US fl oz			
1 m ³ = 264.172 US gal					
1 litre = 0.264 172 US gal = 35.195 fl oz = 33.814 US fl oz		1 Imp gal = 160 fl oz = 277.42 in ³ = 1.2010 US gal = 153.72 US fl oz = 4546.1 cm ³ or ml = 4.546 litres			
1 in ³ = 16.3871 cm ³ or ml = 0.576 744 fl oz = 0.554 113 US fl oz		1 US gal = 231 in ³ = 128 US fl oz = 133.23 UK fl oz = 0.832 67 Imp gal = 3785.41 cm ³ or ml = 3.7854 litres			

Density

	<i>To obtain:</i> g/cm³	lb/ft³	lb/Imp gal	lb/US gal
<i>Multiply no. of</i>				
g/cm³ by	1	62.43	10.02	8.345
lb/ft³ by	0.016 02	1	0.1605	0.1337
lb/Imp gal by	0.100	6.229	1	1.2010
lb/US gal by	0.1198	7.481	0.83267	1
<hr/>				
1 mg/m ³ = 1000 mg/litre = 35.314 mg/ft ³				
1 mg/ft ³ = 28.32 mg/litre = 0.028 32 mg/m ³				
1 lb/Imp gal = 1.2010 lb/US gal 1 lb/US gal = 0.832 67 lb/Imp gal				

Viscosity**Dynamic** (20°C)

centipoise	× 0.001	= N s/m ² = Pa s
newton second per m ²	× 1000	= centipoise
poise	× 0.1	= N s/m ² = Pa s
pound force second per ft ²	× 47 880 × 47.880	= centipoise = Pa s

Kinematic (20°C)

centistoke	× 1	= mm ² /s
ft ² /hr	× 25.807	= centistokes
	× 0.092 90	= m ² /hr
m ² /hr	× 10.764	= ft ² /hr

Pressure

<i>To obtain:</i>		MPa (N/mm ²)	atm	mm Hg	psi (lb/in ²)	lb/ft ²
	bar					
<i>Multiply no. of</i>						
bar by	1	0.1	1.013 25	7.5006×10^2	14.5038	2088.54
MPa by	10	1	10.1325	7.5006×10^3	145.0377	20 885.4
atm by	0.986 9233	0.098 6923	1	760.0	14.696	2116
mm Hg by	133.322×10^{-5}	133.322×10^{-6}	0.0013	1	0.019 34	2.785
psi by	$6.894 76 \times 10^{-2}$	$6.894 76 \times 10^{-3}$	0.068	51.71	1	144
lb/ft² by	4.788×10^{-4}	0.4788×10^{-4}	4.72×10^{-4}	0.359	0.0069	1

Radiant energy units

	<i>To obtain:</i> erg	joule	W s	μW s	g cal
<i>Multiply no. of</i>					
erg by	1	10^{-7}	10^{-7}	0.1	2.39×10^{-8}
joule by	10^7	1	1	10^6	0.239
W s by	10^7	1	1	10^6	0.239
μW s by	10	10^{-6}	10^{-6}	1	2.39×10^{-7}
g cal by	4.19×10^7	4.19	4.19	4.19×10^6	1

Flow rates

	<i>To obtain:</i> litres/min	m ³ /hr	Imp gal/min	US gal/min	ft ³ /min	ft ³ /s
<i>Multiply no. of</i>						
litres/min by	1	0.06	0.2200	0.2642	0.0353	5.89×10^{-4}
m³/hr by	16.67	1	3.7	4.4	0.588	9.89×10^{-3}
Imp gal/min by	4.55	0.273	1	1.2010	0.1605	2.67×10^{-3}
US gal/min by	3.78	0.227	0.832 67	1	0.1338	2.23×10^{-3}
ft³/min by	28.32	1.699	6.23	7.50	1	0.016 67
ft³/s by	1699	102	373.7	448.8	60	1

**Energy/unit area
(dose units)**

	<i>To obtain:</i> erg/cm ²	joule/cm ²	W s/cm ²	μW s/cm ²	g cal/cm ²
<i>Multiply no. of</i>					
erg/cm² by	1	10^{-7}	10^{-7}	0.1	2.39×10^{-8}
joule/cm² by	10^7	1	1	10^6	0.239
W s/cm² by	10^7	1	1	10^6	0.239
μW s/cm² by	10	10^{-6}	10^{-6}	1	2.39×10^{-7}
g cal/cm² by	4.19×10^7	4.19	4.19	4.19×10^6	1

Concentration

mg/litre in water (specific gravity = 1.0)	× 1.0 × 0.001 × 0.070157 × 0.058418 × 6.95 × 8.35	= ppm or g/m ³ = g/litre = grains per Imp gal = grains per US gal = lb per million Imp gal = lb per million US gal
mg/kg	× 0.002 × 0.0018	= lb/ton (short) = lb/ton (long)

Emission rates

	<i>To obtain:</i>						
	g/s	g/min	kg/hr	kg/day	lb/min	lb/hr	lb/day
<i>Multiply no. of</i>							
g/s by	1.0	60.0	3.6	86.40	0.132 28	7.9367	190.48
g/min by	0.016 667	1.0	0.06	1.4400	2.2046×10^{-3}	0.132 28	3.1747
kg/hr by	0.277 78	16.667	1.0	24.000	0.036 744	2.2046	52.911
kg/day by	0.011 574	0.694 44	0.041 667	1.0	1.5310×10^{-3}	9.1860×10^{-2}	2.2046
lb/min by	7.5598	453.59	27.215	653.17	1.0	60.0	1440
lb/hr by	0.126 00	7.5598	0.453 59	10.886	1.6667×10^{-2}	1.0	24.0
lb/day by	5.2499×10^{-3}	0.314 99	1.8900×10^{-2}	0.453 59	6.9444×10^{-4}	4.1667×10^{-2}	1.0

Heat, energy or work

	<i>To obtain:</i>						
	joule	ft lb	kW hr	hp hr	kcal	cal	Btu
<i>Multiply no. of</i>							
joules by	1	0.737	2.773×10^{-7}	3.725×10^{-7}	2.39×10^{-4}	0.2390	9.478×10^{-4}
ft lb by	1.356	1	3.766×10^{-7}	5.05×10^{-7}	3.24×10^{-4}	0.3241	1.285×10^{-3}
kW hr by	3.6×10^6	2.66×10^6	1	1.341	860.57	860 565	3412
hp hr by	2.68×10^6	1.98×10^6	0.7455	1	641.62	641 615	2545
kcal by	4184	3086	1.162×10^{-3}	1.558×10^{-3}	1	1000	3.9657
cal by	4.184	3.086	1.162×10^{-6}	1.558×10^{-6}	0.001	1	0.003 97
Btu by	1055	778.16	2.930×10^{-4}	3.93×10^{-4}	0.252	252	1

Velocity

	<i>To obtain:</i> cm/s	m/s	km/hr	ft/s	ft/min	mph
<i>Multiply no. of</i>						
cm/s by	1	0.01	0.036	0.0328	1.968	0.022 37
m/s by	100	1	3.6	3.281	196.85	2.237
km/hr by	27.78	0.2778	1	0.9113	54.68	0.6214
ft/s by	30.48	0.3048	18.29	1	60	0.6818
ft/min by	0.5080	0.005 08	0.0183	0.0166	1	0.011 36
mph by	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

Bibliography

- Alderson, M.R. (1986) *Occupational Cancer*, Butterworths, London.
- American Conference of Governmental Industrial Hygienists (1990) *Threshold Limit Values for Chemical Substances in the Work Environment*, ACGIH, Cincinnati.
- Bartknecht, W. (1981) *Explosions*, Springer-Verlag, New York.
- Bond, J. (1991) *Sources of Ignition – Flammability Characteristics of Chemicals and Products*, Butterworth-Heinemann, Oxford.
- Bourdeau, P., and Green, G. (1989) *Methods for Assessing and Reducing Injury from Chemical Accidents*, Wiley, Chichester.
- Bretherick, L. (1992) *Hazards in the Chemical Laboratory*, 5th edn, S.G. Luxon (ed.), Royal Society of Chemistry, Cambridge.
- Bretherick, L. (1990) *Handbook of Reactive Chemical Hazards*, 4th edn, Butterworth-Heinemann, Oxford.
- Bridgewater, A.V., and Mumford, C.J. (1979) *Waste Recycling and Pollution Control Handbook*, George Godwin, London.
- British Cryogenics Council (1991) *Cryogenics Safety Manual*, 3rd edn, Butterworth-Heinemann, Oxford.
- British Occupational Hygiene Society (1985) *The Selection and Use of Personal Sampling Pumps*, Technical Guide No. 5, BOHS, Norwood, Science Reviews.
- British Occupational Hygiene Society (1988) *Controlling Airborne Contaminants in the Workplace*, Technical Guide No. 7, BOHS, Norwood, Science Reviews.
- British Occupational Hygiene Technology Committee (1975) *Guide to the Design and Installation of Laboratory Fume Cupboards*.
- Browning, E. (1965) *Toxicity and Metabolism of Industrial Solvents*, Elsevier, Amsterdam.
- Carson, P.A., and Mumford, C.J. (1988) *The Safe Handling of Chemicals in Industry*, 2 vols, Longman, Harlow.
- Carson, P.A., and Dent, N.J. (ed.) (1990) *Good Laboratory and Clinical Practices*, Heinemann Newnes, Oxford.
- Chemical Industries Association (1975) *Safety Audits – A Guide for the Chemical Industry*, London.
- Chemical and Process Industries Training Board (1977) *Permit to Work Systems*, CAPITB-16, London.
- Cheremisinoff, P.N. (1992) *Waste Incineration Handbook*, Butterworth-Heinemann, Oxford.
- Clayton, G.D., and Clayton, F.E. (ed.) (1982) *Patty's Industrial Hygiene and Toxicology*, 3rd edn, Wiley, New York.
- Cox, S.J., and Tait, N.R.S. (1991) *Reliability, Safety and Risk Management: An Integrated Approach*, Butterworth-Heinemann, Oxford.
- Cralley, L.V., and Cralley, L.L. (ed.) (1983/84) *Industrial Hygiene Aspects of Plant Operations*, 3 vols, Macmillan, New York.
- Cullis, C.F. and Firth, J.G. (ed.) (1988) *Detection and Measurement of Hazardous Gases*, Heinemann, London.
- Everett, K., and Hughes, D. (1981) *A Guide to Laboratory Design*, 2nd edn, Butterworths, London.
- Fawcett, H.H., and Woods, W.S. (ed.) (1982) *Safety and Accident Prevention in Chemical Operations*, 2nd edn, Wiley, Chichester.
- Fire Protection Association (1977a) *Fire and Related Properties of Industrial Chemicals*, London.
- Fire Protection Association (1977b) *Guide to Fire Precautions with Outside Contractors*, London.

- Harrison, R.M. (ed.) (1990) *Pollution: Causes, Effects and Control*, 2nd edn, Royal Society of Chemistry, Cambridge.
- Harvey, B. (ed.) (1990) *Handbook of Occupational Hygiene*, Croner Publications, New Malden.
- High Pressure Technology Association (1975) *High Pressure Safety Code*, Leeds.
- Hughes, J.R. (1970) *Storage and Handling of Petroleum Liquids – Practice and Law*, 2nd edn, Griffin, London.
- Institution of Chemical Engineers (1983) *The Preparation of Plant for Maintenance*, London.
- Institution of Chemical Engineers (1987) *User Guide for the Safe Operation of Centrifuges*, London.
- Institution of Chemical Engineers (1990) *Prevention of Fires and Explosions in Dryers: A User Guide*, 2nd edn, London.
- International Atomic Energy Agency, *Safe Handling of Radioisotopes*, Safety Series No. 1, Vienna.
- King, R.W., and Magid, J. (1979) *Industrial Hazard and Safety Handbook*, Newnes-Butterworth, London.
- Kletz, T.A. (1983) *HAZOP and HAZAN – Notes on the Identification and Assessment of Hazards*, Instn of Chem. Eng., London.
- Kletz, T.A. (1985) *What Went Wrong?*, Gulf Publishing, Houston.
- Kneip, T.J., and Crable, J.V. (ed.) (1988) *Methods for Biological Monitoring*, American Public Health Assoc., Washington DC.
- Lees, F.P., and Ang, M.L. (1989) *Safety Cases Within the Control of Industrial Major (CIMAH) Regulations 1984*, Butterworth, London.
- Lioy, P.J., and Lioy, M.J.Y. (1989) *Air Sampling Instruments*, ACGIH, Cincinnati.
- Lunn, G.A. (1984) *Venting Gas and Dust Explosions – A Review*, Instn of Chem. Eng., London.
- Major, D.W., and Fitchko, J. (1992) *Hazardous Waste Treatment On-site and In Situ*, Butterworth-Heinemann, Oxford.
- Manufacturing Chemists Association (1970) *Laboratory Waste Disposal Manual*, Washington, DC.
- Manufacturing Chemists Association (1972) *Guide for Safety in the Chemical Laboratory*, Van Nostrand Reinhold, New York.
- Martin, W., Lippitt, J.M., and Prothero, T.G. (1992) *Hazardous Waste Handbook for Health and Safety*, Butterworth-Heinemann, Oxford.
- Mecklenburgh, J.C. (ed.) (1985) *Process Plant Layout*, 2nd edn, Longman, Harlow.
- Meidl, J.H. (1970) *Explosive and Toxic Hazardous Materials*, Glencoe, Westerville, OH.
- National Institute for Occupational Safety and Health (1984) *Manual of Analytical Methods*, US Department of Health and Human Services, Washington, DC.
- Oil Insurance Association, *General Recommendations for Spacing in Refineries, Petrochemical Plants, Gasoline Plants, Terminals, Oil Pump Stations and Offshore Properties* (No. 361), USA.
- Palmer, K.N. (1973) *Dust Explosions and Fires*, Chapman and Hall, London.
- Porteous, A. (ed.) (1985) *Hazardous Waste Management Handbook*, Butterworths, London.
- Richardson, M.L. (ed.) (1991) *Chemistry, Agriculture and the Environment*, The Royal Society of Chemistry, London.
- Richardson, M.L. (ed.) (1986) *Toxic Hazard Assessment of Chemicals*, The Royal Society of Chemistry, London.
- Richardson, M.L. (1986) *Risk Assessment for Hazardous Installations*, Pergamon, Oxford.
- Richardson, M.L. (ed.) (1988) *Risk Assessment of Chemicals in the Environment*, The Royal Society of Chemistry, London.
- Ridley, J. (ed.) (1990) *Safety at Work*, 3rd edn, Butterworth-Heinemann, Oxford.
- Royal Society of Chemistry (1977) *Code of Practice for Chemical Laboratories*, London.
- Royal Society of Chemistry (1989) *COSHH in Laboratories*, London.
- St John Ambulance Association, St Andrews Ambulance Association and The British Red Cross Society (1982) *First Aid*, 3rd edn, London.
- Sax, N.I., and Lewis, R.J. (1988) *Dangerous Properties of Industrial Materials*, 7th edn, Van Nostrand Reinhold, New York.
- Schieler, L., and Pauze, D. (1976) *Hazardous Materials*, Van Nostrand Reinhold, Wokingham.
- Schofield, D. (1984) *User Guide to Explosion Prevention and Protection, Pt 2*, Instn of Chem. Eng., London.
- Shapton, D.A., and Board, R.G. (1972) *Safety in Microbiology*, Academic Press, London.
- Simpson, D., and Simpson, W.G. (ed.) (1991) *The COSHH Regulations: A Practical Guide*, The Royal Society of Chemistry, Cambridge.
- Sittig, M. (1981) *Handbook of Toxic and Hazardous Chemicals*, Noyes Publications, Park Ridge, NJ.
- T'So, P.O., and Di Paulo, J.A. (1974) *Chemical Carcinogenesis*, Marcel Dekker, New York.
- Warren, P.J. (ed.) (1985) *Dangerous Chemicals, Emergency Spillage Guide*, Walters Samson (UK), New Malden, Surrey.

Codes of Practice approved by the UK Health and Safety Commission (HMSO)

COP3	Asbestos: Work with asbestos insulation, asbestos coating and asbestos insulating board.
COP21	Asbestos: Control of asbestos at work.
L5	COSHH: Control of substances hazardous to health: Control of carcinogenic substances.
COP30	COSHH: Control of substances hazardous to health in fumigation operations.
COP22	Dangerous substances: Classification and labelling of substances dangerous for supply.
COP42	First aid at work.
COP16	Ionising radiations (parts 1 and 2): Protection of persons against ionising radiation arising from any work activity.
COP23	Ionising radiations (part 3): Exposure to radon.
L7	Ionising radiations (part 4): Dose limitation – restriction of exposure.
L8	Legionnaires' disease: prevention or control of legionellosis (including legionnaires' disease).
COP2	Lead: Control of lead at work.
COP7	New substances: Principles of good laboratory practice: Notification of New Substances Regulations 1982.
L9	Pesticides: safe use of pesticides for non-agricultural purposes.
COP41	Potteries: Control of substances hazardous to health in the production of pottery.
COP31	Vinyl chloride: Control of vinyl chloride at work.

UK Health and Safety Executive publications

HSE (1977) *Code of Practice for the Bulk Storage of Liquid Oxygen at Production Sites.*

Selected HSE health and safety guidance notes

Chemical safety

CS1	Industrial use of flammable gas detectors.
CS2	Storage of highly flammable liquids.
CS3	Storage and use of sodium chlorate and other similar strong oxidants.
CS4	Keeping of LPG in cylinders and similar containers.
CS5	Storage and use of LPG at fixed installations
CS6	Storage and use of LPG on construction sites.
CS7	Odourisation of bulk oxygen supplies in shipyards.
CS8	Small scale storage and display of LPG at retail premises.
CS9	Bulk storage and use of liquid carbon dioxide: hazards and procedures.
CS10	Fumigation using phosphine.
CS11	Storage and use of LPG at metered estates.
CS12	Fumigation using methyl bromide (bromomethane).
CS15	Cleaning and gas freeing of tanks containing flammable residues.
CS16	Chlorine vaporisers.
CS18	Storage and handling of ammonium nitrate.
CS19	Storage of approved pesticides: guidance for farmers and other professional users.
CS20	Sulphuric acid used in agriculture.
CS21	Storage and handling of organic peroxides.

General series

- GS3 Fire risk in the storage and industrial use of cellular plastics.
GS4 Safety in pressure testing.
GS5 Entry into confined spaces.
GS16 Gaseous fire extinguishing systems: precautions for toxic and asphyxiating hazards.
GS18 Commercial ultra-violet tanning equipment.
GS21 Assessment of the radio frequency ignition hazard to process plants where flammable atmospheres may occur.
GS46 In situ timber treatment using timber preservatives.

Medical series

- MS3 Skin tests in dermatitis and occupational chest diseases.
MS4 Organic dust surveys.
MS5 Lung function.
MS6 Chest X-rays in dust diseases.
MS7 Colour vision.
MS9 Byssinosis.
MS12 Mercury – medical surveillance.
MS13 Asbestos.
MS15 Welding.
MS16 Training of offshore sick-bay attendants ('rig-medics').
MS17 Biological monitoring of workers exposed to organo-phosphorus pesticides.
MS21 Precautions for the safe handling of cytotoxic drugs.
MS22 Medical monitoring of workers exposed to platinum salts.
MS23 Health aspects of job placement and rehabilitation: advice to employers.
MS24 Health surveillance of occupational skin disease.
MS25 Medical aspects of occupational asthma.

Environmental hygiene series

- EH1 Cadmium: health and safety precautions.
EH2 Chromium and its inorganic compounds: health and safety precautions.
EH4 Aniline: health and safety precautions.
EH6 Chromic acid concentrations in air.
EH7 Petroleum based adhesives in building operations.
EH8 Arsenic: toxic hazards and precautions.
EH9 Spraying of highly flammable liquids.
EH10 Asbestos: exposure limits and measurement of airborne dust concentrations.
EH11 Arsine: health and safety precautions.
EH12 Stibine: health and safety precautions.
EH13 Beryllium: health and safety precautions.
EH17 Mercury: health and safety precautions.
EH19 Antimony: health and safety precautions.
EH20 Phosphine: health and safety precautions.
EH21 Carbon dust: health and safety precautions.
EH22 Ventilation of the workplace.
EH23 Anthrax: health hazards.
EH24 Dust and accidents in malhousers.
EH25 Cotton dust sampling.
EH27 Acrylonitrile: personal protective equipment.
EH28 Control of lead: air sampling techniques and strategies.
EH29 Control of lead: outside workers.
EH31 Control of exposure to polyvinyl chloride dust.

EH33	Atmospheric pollution in car parks.
EH34	Benzidine based dyes: health and safety precautions.
EH35	Probable asbestos dust concentrations at construction processes.
EH36	Work with asbestos cement.
EH37	Work with asbestos insulation board.
EH38	Ozone: health hazards and precautionary measures.
EH40	Occupational Exposure Limits (revised annually).
EH41	Respiratory protective equipment for use against asbestos.
EH42	Monitoring strategies for toxic substances.
EH43	Carbon monoxide.
EH44	Dust: General principles of protection.
EH45	Carbon disulphide: control of exposure in the viscose industry.
EH46	Man-made mineral fibres.
EH47	Provision, use and maintenance of hygiene facilities for work with asbestos insulation and coatings.
EH49	Nitrosamines in synthetic metal cutting and grinding fluids.
EH50	Training operatives and supervisors for work with asbestos insulations and coatings.
EH51	Enclosures provided for work with asbestos insulation, coatings and insulating board.
EH52	Removal techniques and associated waste handling for asbestos insulation, coatings and insulating board.
EH53	Respiratory protective equipment against airborne radioactivity.
EH54	Assessment of exposure to fume from welding and allied processes.
EH55	Control of exposure to fume from welding, brazing and similar processes.
EH56	Biological monitoring for chemical exposures in the workplace.
EH58	The carcinogenicity of mineral oils.
EH59	Crystalline silica.
EH60	Nickel and its inorganic compounds: health and safety precautions.
EH62	Metalworking fluids: health precautions.

Health and safety executive leaflets

HSE8	Fires and explosions due to the misuse of oxygen.
HSE11	Reporting an injury or a dangerous occurrence.
HSE17	Reporting a case of disease: a brief guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985.

Health and safety guidance booklets

HS(G)1	Safe use and storage of flexible polyurethane foam.
HS(G)5	Hot work: welding and cutting on plant containing flammable materials.
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)16	Evaporating and other ovens.
HS(G)22	Electrical apparatus for use in potentially explosive atmospheres.
HS(G)27	Substances for use at work: the provision of information.
HS(G)34	Storage of LPG at fixed installations.
HS(G)40	Chlorine from drums and cylinders.
HS(G)50	Storage of flammable liquids in fixed tanks (up to 10 000 m ³ total capacity).
HS(G)51	Storage of flammable liquids in containers.
HS(G)53	Respiratory protective equipment: a practical guide for users.
HS(G)54	The maintenance, examination and testing of local exhaust ventilation.
HS(G)56	Noise at work: noise assessment, information and control.
HS(G)61	Surveillance of people exposed to health risks at work.
HS(G)62	Health and safety in tyre and exhaust fitting premises.

HS(G)70	Control of legionellosis including legionnaires' disease.
HS(G)71	Storage of packaged dangerous substances
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.

Health and safety regulation booklets

HS(R)1	Packaging and labelling of dangerous substances — regulations and guidance notes.
L1	Guide to the Health and Safety at Work etc. Act 1974.
HS(R)12	Guide to the Health and Safety (Dangerous Pathogens) Regulations 1981.
HS(R)14	Guide to the Notification of New Substances Regulations.
HS(R)15	Administrative guidance on the implementation of the European Community 'Explosive Atmospheres' Directive.
HS(R)16	The Notification of Installations Handling Hazardous Substances Regulations 1982.
HS(R)17	The Classification and Labelling of Explosives Regulations 1983.
HS(R)19	Guide to the Asbestos (Licensing) Regulations 1983.
HS(R)22	Guide to the Classification, Packaging and Labelling of Dangerous Substances Regulations 1984.
HS(R)23	Guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1985.

Methods for the determination of hazardous substances

MDHS1	Acrylonitrile in air (charcoal adsorption tubes).
MDHS2	Acrylonitrile in air (porous polymer adsorption tubes).
MDHS3	Generation of test atmospheres of organic vapours by the syringe injection technique.
MDHS4	Generation of test atmospheres of organic vapours by the permeation tube method.
MDHS5	On-site validation of sampling methods.
MDHS6	Lead and inorganic compounds of lead in air (atomic absorption spectroscopy).
MDHS7	Lead and inorganic compounds of lead in air (X-ray fluorescence spectroscopy).
MDHS8	Lead and inorganic compounds of lead in air (colorimetric field method).
MDHS9	Tetra alkyl lead compounds in air (personal monitoring).
MDHS10	Cadmium and inorganic compounds of cadmium in air (atomic absorption spectrometry).
MDHS11	Cadmium and inorganic compounds of cadmium in air (X-ray fluorescence spectroscopy).
MDHS12	Chromium and inorganic compounds of chromium in air (atomic absorption spectrometry).
MDHS13	Chromium and inorganic compounds of chromium in air (X-ray fluorescence spectroscopy).
MDHS14	General methods for the gravimetric determination of respirable and total inhalable dust.
MDHS15	Carbon disulphide in air.
MDHS16	Mercury vapour in air (hopcalite adsorbent tubes).
MDHS17	Benzene in air (charcoal adsorbent tubes).
MDHS18	Tetra alkyl lead compounds in air (continuous on-site monitoring).
MDHS19	Formaldehyde in air.
MDHS20	Styrene in air.
MDHS21	Glycol ether and glycol ether acetate vapours in air (charcoal adsorbent tubes).
MDHS22	Benzene in air (porous polymer adsorbent tubes).
MDHS23	Glycol ether acetate vapours in air (Tenax adsorbent tubes).
MDHS24	Vinyl chloride in air.
MDHS25	Organic isocyanates in air.
MDHS26	Ethylene oxide in air.
MDHS27	Protocol for assessing the performance of a diffusive sampler.
MDHS28	Chlorinated hydrocarbon solvent vapours in air.
MDHS29	Beryllium and inorganic compounds of beryllium in air.
MDHS30	Cobalt and inorganic compounds of cobalt in air.
MDHS31	Styrene in air (porous polymer adsorbent tubes, thermal desorption and gas chromatography).

MDHS32	Diethylphthalates in air (Tenax adsorbent tubes, solvent desorption and gas chromatography).
MDHS33	Adsorbent tube standards (preparation by the syringe loading technique).
MDHS34	Arsine in air.
MDHS35	Hydrogen fluoride and inorganic fluorides in air (using an ion selective electrode).
MDHS36	Toluene in air (pumped charcoal adsorption tubes, solvent desorption and gas chromatography).
MDHS37	Quartz in respirable airborne dusts (direct method).
MDHS38	Quartz in respirable airborne dusts (KBr disc technique).
MDHS39	Asbestos fibres in air.
MDHS40	Toluene in air (porous polymer adsorbent tubes).
MDHS41	Arsenic and inorganic compounds of arsenic in air (atomic absorption spectrometry).
MDHS42	Nickel and inorganic compounds of nickel in air.
MDHS43	Styrene in air (porous polymer diffusive samplers, thermal desorption and gas chromatography).
MDHS44	Styrene in air (charcoal diffusive samplers, solvent desorption and gas chromatography).
MDHS45	Ethylene dibromide in air.
MDHS46	Platinum metal and soluble inorganic compounds of platinum in air.
MDHS47	Rubber fumes in air, measured as 'total particles' and 'cyclohexane soluble material'.
MDHS48	Newspaper print rooms: measurement of total particulates and cyclohexane soluble material in air.
MDHS49	Aromatic isocyanates in air.
MDHS50	Benzene in air (porous polymer diffusion samplers, thermal desorption and gas chromatography).
MDHS51	Quartz in respirable airborne dusts (X-ray diffraction).
MDHS52	Soluble hexavalent chromium compounds in air.
MDHS53	1,3-Butadiene in air (pumped molecular sieve absorbent tubes, thermal desorption and gas chromatography).
MDHS54	Protocol for assessing the performance of a pumped sampler for gases and vapours.
MDHS55	Acrylonitrile in air (porous polymer diffusion samplers, thermal desorption and gas chromatography).
MDHS56	Hydrogen cyanide in air.
MDHS57	Acrylamide in air.
MDHS58	Mercury vapour in air (diffusive samplers).
MDHS59	Man-made mineral fibre.
MDHS60	Mixed hydrocarbons (C3 to C10) in air.
MDHS61	Total hexavalent chromium compounds in air.
MDHS62	Aromatic carboxylic acid anhydrides in air.
MDHS63	1,3-Butadiene in air (molecular sieve diffusion samplers, thermal desorption and gas chromatography).
MDHS64	Toluene in air (charcoal diffusive samplers, solvent desorption and gas chromatography).
MDHS66	Mixed hydrocarbons (C5 to C10) in air.
MDHS67	Total chromium in chromium plating mists.
MDHS68	Coal tar pitch volatiles (measurement of particulates and cyclohexane-soluble material in air).
MDHS69	Toluene in air (charcoal diffusive samplers, solvent desorption and gas chromatography).
MDHS70	General methods for sampling airborne gases and vapours.
MDHS71	Analytical quality in workplace air monitoring.
MDHS72	Volatile organic compounds in air.
MDHS73	Measurement of air change rates in factories and offices.

Toxicity reviews

TR1	Styrene.
TR2	Formaldehyde.

TR3	Carbon disulphide.
TR4	Benzene.
TR5	Pentachlorophenol.
TR6	Trichloroethylene.
TR7	Cadmium and its compounds.
TR8	Trimellitic anhydride (TMA), 4,4'-methylenebis (2-chloroaniline) (MBOCA), <i>N</i> -nitrosodiethanolamine (NDELA).
TR9	1,1,1-Trichloroethane.
TR10	Glycol ethers.
TR11	1,3-Butadiene and related compounds.
TR12	Dichloromethane (methylene chloride).
TR13	Vinylidene chloride.
TR14	Review of the toxicity of the esters of <i>o</i> -phthalic acid (phthalate esters).
TR15	Carcinogenic hazard of wood dusts, carcinogenicity of crystalline silica.
TR16	Inorganic arsenic compounds.
TR17	Tetrachloroethylene (tetrachloroethene, perchloroethylene).
TR18	<i>n</i> -Hexane.
TR19	Toxicity of nickel and its inorganic compounds.
TR20	Toluene.
TR21	Chromium.
TR22	Bis(chloromethyl)ether.
TR24	Ammonia. 1-Chloro-2,3-epoxypropane (epichlorohydrin). Carcinogenicity of cadmium and its compounds.
TR25	Cyclohexane. Cumene. <i>para</i> -Dichlorobenzene (<i>p</i> -DCB). Chlorodifluoromethane (CFC 22).
TR26	Xylenes.

Selected British Standards

BS349	Identification of contents of industrial gas cylinders.
BS476	Part 8: Test methods and criteria for the fire-resistance of elements of building construction.
BS638	Arc welding power sources, equipment and accessories. Part 9: Specification for power sources for manual arc welding with limited duty.
BS679	Specification for filters, cover lenses and backing lenses for use during welding and similar operations.
BS697	Specification for rubber gloves for electrical purposes.
BS1319	Colour coding for medical gas cylinders.
BS1542	Equipment for protection during welding.
BS1547	Flameproof industrial clothing.
BS1651	Industrial gloves.
BS1747	Methods for measurement of air pollution (8 parts).
BS1870	Safety footwear.
BS2091	Dust respirators.
BS2092	Eye protectors.
BS2653	Protective clothing for welders.
BS3016	Specification for pressure regulators and automatic changeover devices for LPG.
BS3314	Specification for protective aprons.
BS3324	Method for determination of vapour pressure of LPG (see also BS3879).
BS3405	Measurement of particulate emissions.
BS3510	Symbols for ionizing radiation.
BS3664	Film badges for personal radiation monitoring.
BS3864	Protective helmets for fire-fighters.
BS4033	Industrial scalp protectors.
BS4089	Hoses and hose assemblies.
BS4275	Selection, use and maintenance of respiratory equipment.
BS4555	High efficiency dust respirators.

- BS4558 Positive pressure powered dust respirators.
BS4667 Breathing apparatus.
BS4676 Gaiters and footwear (foundries).
BS4771 Positive pressure powered dust hoods and blouses.
BS5045 Transportable gas containers.
BS5120 Rubber hose for gas welding.
BS5145 Rubber boots.
BS5240 Industrial safety helmets.
BS5306 Fire extinguishing installations and equipment.
BS5343 Gas detector tubes.
BS5345 Installation and maintenance of electrical apparatus for use in potentially explosive atmospheres.

BS5378 Safety signs and colours.
BS5423 Specification for portable fire extinguishers.
BS5426 Work wear.
BS5501 Electrical apparatus for potentially explosive atmospheres.
BS5588 Fire precautions in the design and construction of buildings.
BS5720 Mechanical ventilation and air conditioning in buildings.
BS5726 Microbiological safety cabinets.
BS5839 Fire detection and alarm systems in buildings.
BS5908 Fire precautions in chemical plant.
BS5924 Construction and installation of equipment for resistance welding.
BS5958 Control of static electricity.
BS6016 Filtering face-piece dust respirators.
BS6069 Characterization of air quality.
BS6090 Personal photographic dosimeters (ionizing radiation).
BS6151 PVC boots.
BS6467 Electrical apparatus for use in presence of combustible dusts.
BS6691 Fume from welding and allied processes (2 parts).
BS6927 Respiratory protective devices (glossary).
BS6928 Respiratory protective devices (classification).
BS6929 Respiratory protective devices (component nomenclature).
BS7004 Respiratory protective devices (self-contained open-circuit).
BS7028 Selection, use and maintenance of eye protection.
BS7156 Respiratory protective devices: threads for facepieces (2 parts).
BS7170 Respiratory protective devices (self-contained closed-circuit).
BS7182 Air-permeable chemical protective clothing.
BS7184 Selection, use and maintenance of chemical protective clothing.
BS7193 Lightweight rubber overshoes.
BS7258 Laboratory fume cupboards (3 parts).
BS7309 Mouthpiece assemblies for respiratory protective devices.
BS7355 Respiratory protective devices (full-face masks).
BS7356 Respiratory protective devices (half- and quarter-masks).

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