OCCUPATIONAL HYGIENE AND RISK MANAGEMENT
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<td>AAS</td>
<td>atomic absorption spectroscopy</td>
</tr>
<tr>
<td>AC</td>
<td>asbestos-cement</td>
</tr>
<tr>
<td>ACGIH</td>
<td>American Conference of Governmental Industrial Hygienists</td>
</tr>
<tr>
<td>ADG Code</td>
<td>Australian Dangerous Goods Code</td>
</tr>
<tr>
<td>AED</td>
<td>aerodynamic equivalent diameter</td>
</tr>
<tr>
<td>AES</td>
<td>atomic emission spectroscopy</td>
</tr>
<tr>
<td>AET</td>
<td>allowable exposure time</td>
</tr>
<tr>
<td>ALARA</td>
<td>as low as reasonably achievable</td>
</tr>
<tr>
<td>AVM</td>
<td>anti-vibration mountings</td>
</tr>
<tr>
<td>BCIRA</td>
<td>British Cast Iron Research Association</td>
</tr>
<tr>
<td>BEI</td>
<td>biological exposure index</td>
</tr>
<tr>
<td>BMRC</td>
<td>British Medical Research Council</td>
</tr>
<tr>
<td>CCA</td>
<td>chromated copper arsenate</td>
</tr>
<tr>
<td>CET</td>
<td>corrected effective temperature</td>
</tr>
<tr>
<td>CFC</td>
<td>chlorinated fluorocarbon</td>
</tr>
<tr>
<td>CNS</td>
<td>central nervous system</td>
</tr>
<tr>
<td>CTD</td>
<td>cumulative trauma disorder</td>
</tr>
<tr>
<td>CTS</td>
<td>carpal tunnel syndrome</td>
</tr>
<tr>
<td>DB</td>
<td>dry bulb</td>
</tr>
<tr>
<td>DNA</td>
<td>deoxyribonucleic acid</td>
</tr>
<tr>
<td>DND</td>
<td>daily noise dose</td>
</tr>
<tr>
<td>DS</td>
<td>dispersion staining</td>
</tr>
<tr>
<td>ECT</td>
<td>equivalent chill temperature</td>
</tr>
<tr>
<td>EMR</td>
<td>electromagnetic radiation</td>
</tr>
<tr>
<td>ET</td>
<td>effective temperature</td>
</tr>
<tr>
<td>ETS</td>
<td>environmental tobacco smoke</td>
</tr>
<tr>
<td>FAM</td>
<td>fibrous aerosol monitor</td>
</tr>
<tr>
<td>GC</td>
<td>gas chromatograph</td>
</tr>
<tr>
<td>GT</td>
<td>globe temperature</td>
</tr>
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<td>HEPA</td>
<td>high efficiency particulate</td>
</tr>
<tr>
<td>HMDI</td>
<td>hexamethylene diisocyanate</td>
</tr>
<tr>
<td>HSE</td>
<td>Health and Safety Executive [UK]</td>
</tr>
<tr>
<td>HSI</td>
<td>heat stress index</td>
</tr>
<tr>
<td>HVAC</td>
<td>heating, ventilation and airconditioning</td>
</tr>
<tr>
<td>IARC</td>
<td>International Agency for Research on Cancer</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>ICP</td>
<td>inductively coupled plasma</td>
</tr>
<tr>
<td>IL</td>
<td>intensity level</td>
</tr>
<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organisation</td>
</tr>
<tr>
<td>LC</td>
<td>lethal concentration</td>
</tr>
<tr>
<td>LD</td>
<td>lethal dose</td>
</tr>
<tr>
<td>LEL</td>
<td>lower explosive limit</td>
</tr>
<tr>
<td>LEV</td>
<td>local exhaust ventilation</td>
</tr>
<tr>
<td>LI</td>
<td>lifting index</td>
</tr>
<tr>
<td>LSC</td>
<td>lumbosacral compressive forces</td>
</tr>
<tr>
<td>MCE</td>
<td>mixed cellulose ester</td>
</tr>
<tr>
<td>MDF</td>
<td>medium density fibreboard</td>
</tr>
<tr>
<td>MDI</td>
<td>methylene bisphenyl isocyanate</td>
</tr>
<tr>
<td>MMH</td>
<td>manual materials handling</td>
</tr>
<tr>
<td>MMMF</td>
<td>man-made mineral fibres</td>
</tr>
<tr>
<td>MMVF</td>
<td>man-made vitreous fibres</td>
</tr>
<tr>
<td>MS</td>
<td>mass spectroscopy</td>
</tr>
<tr>
<td>MSDS</td>
<td>material safety data sheet</td>
</tr>
<tr>
<td>NATA</td>
<td>National Association of Testing Authorities</td>
</tr>
<tr>
<td>NES</td>
<td>national exposure standards</td>
</tr>
<tr>
<td>NH&amp;MRC</td>
<td>National Health and Medical Research Council</td>
</tr>
<tr>
<td>NIOSH</td>
<td>National Institute of Occupational Safety and Health [US]</td>
</tr>
<tr>
<td>NOHSC</td>
<td>National Occupational Health and Safety Commission</td>
</tr>
<tr>
<td>NTP</td>
<td>normal temperature and pressure</td>
</tr>
<tr>
<td>NWB</td>
<td>natural wet bulb</td>
</tr>
<tr>
<td>OEL</td>
<td>occupational exposure limits [UK]</td>
</tr>
<tr>
<td>OHSMS</td>
<td>occupational health and safety management system</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Authority [US]</td>
</tr>
<tr>
<td>P4SR</td>
<td>predicted 4-hour sweat rate</td>
</tr>
<tr>
<td>PAH</td>
<td>polycyclic aromatic hydrocarbon</td>
</tr>
<tr>
<td>PAPR</td>
<td>powered air-purifying respirator</td>
</tr>
<tr>
<td>PEFR</td>
<td>peak expiratory flow rate</td>
</tr>
<tr>
<td>PEL</td>
<td>permissible exposure limits</td>
</tr>
<tr>
<td>PLM</td>
<td>polarising light microscopy</td>
</tr>
<tr>
<td>PMF</td>
<td>progressive massive fibrosis</td>
</tr>
<tr>
<td>PND</td>
<td>partial noise dose</td>
</tr>
<tr>
<td>PNS</td>
<td>peripheral nervous system</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protective equipment</td>
</tr>
<tr>
<td>PSEM</td>
<td>personal sound exposure meter</td>
</tr>
<tr>
<td>PTBP</td>
<td>p-tert-butylphenol</td>
</tr>
<tr>
<td>PTS</td>
<td>permanent threshold shift</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>RAM</td>
<td>real-time aerosol monitor</td>
</tr>
<tr>
<td>RBC</td>
<td>red blood cell</td>
</tr>
<tr>
<td>RCF</td>
<td>refractory ceramic fibre</td>
</tr>
<tr>
<td>REL</td>
<td>recommended exposure limit</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<td>--------------</td>
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</tr>
<tr>
<td>RF</td>
<td>radio frequency</td>
</tr>
<tr>
<td>RH</td>
<td>relative humidity</td>
</tr>
<tr>
<td>RIS</td>
<td>regulatory impact statement</td>
</tr>
<tr>
<td>RMPF</td>
<td>required minimum protection factor</td>
</tr>
<tr>
<td>RPE</td>
<td>respiratory protection equipment</td>
</tr>
<tr>
<td>RSI</td>
<td>repetitive strain injury</td>
</tr>
<tr>
<td>RT</td>
<td>radiant temperature</td>
</tr>
<tr>
<td>RULA</td>
<td>rapid upper limb assessment</td>
</tr>
<tr>
<td>RWL</td>
<td>recommended weight limit</td>
</tr>
<tr>
<td>SBS</td>
<td>sick building syndrome</td>
</tr>
<tr>
<td>SI</td>
<td>International System of Units</td>
</tr>
<tr>
<td>Simpeds</td>
<td>Safety in Mines Research Establishment</td>
</tr>
<tr>
<td>SLM</td>
<td>sound level meter</td>
</tr>
<tr>
<td>SMF</td>
<td>synthetic mineral fibre</td>
</tr>
<tr>
<td>SMR</td>
<td>standard mortality rate</td>
</tr>
<tr>
<td>SOP</td>
<td>standard operating procedure</td>
</tr>
<tr>
<td>SPL</td>
<td>sound pressure level</td>
</tr>
<tr>
<td>STEL</td>
<td>short-term exposure limit</td>
</tr>
<tr>
<td>STP</td>
<td>standard temperature and pressure</td>
</tr>
<tr>
<td>SWOT</td>
<td>strengths, weaknesses, opportunities and threats</td>
</tr>
<tr>
<td>TDI</td>
<td>toluene 2,4 diisocyanate</td>
</tr>
<tr>
<td>TLD</td>
<td>thermoluminescent dosimeter</td>
</tr>
<tr>
<td>TTS</td>
<td>temporary threshold shift</td>
</tr>
<tr>
<td>TWA</td>
<td>time-weighted average</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>VIRA</td>
<td>video recording analysis</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compound</td>
</tr>
<tr>
<td>WB</td>
<td>wet bulb</td>
</tr>
<tr>
<td>WBGT</td>
<td>wet bulb globe temperature</td>
</tr>
<tr>
<td>WRULD</td>
<td>work-related upper limb disorder</td>
</tr>
<tr>
<td>XRD</td>
<td>X-ray diffractometry</td>
</tr>
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</table>
As awareness of the importance of minimising occupational health and safety risk continues to grow amongst Australian employers, so too does the science of occupational hygiene. Occupational hygiene hazards such as dusts, noise, chemicals, vibration, radiation, ergonomics, light, pressure and biological agents require an especially diligent approach to ensure they are not only identified, but the level of risk assessed and appropriate controls put in place for the long-term health of workers. Unfortunately, history shows situations where occupational hygiene risks have not been well managed: for instance, exposure to crocidolite (blue) asbestos during mining operations in Western Australia resulting in death from mesothelioma, a highly aggressive cancer of the lung pleura, is not expected to peak for another two decades. What about the effects of stonemasons' exposure to crystalline silica, excessive noise at concerts, vibration in heavy vehicles or exposure to mercury from broken thermometers in hospitals or formaldehyde in newly refurbished office buildings?

This chapter will define the term occupational hygiene, the principles of risk management and the difference between hazard and risk. It will also provide an introduction to toxicology, the concept of dose, exposure and epidemiology. Occupational exposure standards and biological exposure indices will be explained and their uses shown with some practical examples.

**OCCUPATIONAL HYGIENE**

For a long time, we have known that work can affect our health. In 1775 Percivall Pott, a surgeon at St Bartholemew’s Hospital, described the occurrence of scrotal cancer in chimney sweeps. It was only later that polycyclic aromatic hydrocarbons (PAH) were identified as the cause. Manufacturing of matches with phosphorous was linked to necrosis of the jaw, felting of animal fur with organic mercury caused neurological changes, use of vinyl chloride monomer in the manufacture of polyvinyl chloride (PVC) caused liver cancer, and benzene from the petroleum refining industry was linked with leukaemia. Studies into the effects of electromagnetic radiation from wireless technologies such as mobile telephones continue to draw mixed conclusions.

Occupational hygiene is aimed at reducing the probability that workers’ health will be affected by work. The term ‘health’ is very broad. It not only considers physical health but also our psychological and emotional wellbeing. For instance, exposure to nickel may cause dermatitis of the skin, which by itself is not life threatening. However, a noticeable rash may lead to a sense of isolation from the community and cause psychological scarring as the worker attempts to escape ridicule or misunderstanding about their condition. Occupational hygiene can be thought of as the identification, evaluation and control of agents...
Case study 1: Identification, evaluation and control

Several workers in a restaurant have reported headaches and feeling drowsy when they serve customers through a driveway window. The serving window is closed when customers have been served and they have driven away. The building is airconditioned.

The occupational hygiene hazard was identified as the gas carbon monoxide (CO), a chemical asphyxiant which is released from motor vehicles. The exposure was evaluated and the ventilation adjusted to reduce exposure.

that can harm a worker’s health. These agents can exist in a number of forms: biological, chemical, ergonomic, physical. Physical hazards can include light, noise, pressure, radiation and vibration. Chemical hazards may be in the form of aerosols, dusts, fibres, fume, gas, mists, smoke or vapours. Bacteria, fungi, protozoan and viruses are examples of biological agents. Shift work, manual handling and occupational stress are considered to be ergonomic hazards.

RISK MANAGEMENT

Effective identification, evaluation and control can manage occupational hygiene hazards. These are also known as the principles of risk management. Identification or recognition of the agent requires knowledge of the workplace and its processes, materials, by-products and outputs. Some practical methods that might assist in correct identification include conducting a walk-through survey of the conditions of the workplace, review of information such as labels or material safety data sheets and discussion with workers. The evaluation stage will consider the probability that exposure will cause harm and the magnitude of this effect. This is also known as assessment or risk assessment. Implementation of controls may depend upon the nature of the agent, cost, feasibility and the results of the evaluation. Once steps have been taken to control exposure, the effectiveness of such interventions should be reviewed.

Following these principles is crucial to the occupational hygiene process. Incorrect identification of the nature or type of occupational hygiene hazards will result in time and resources being spent investigating aspects that may not in fact require it. Equally, if the agent is not evaluated against valid criteria, the potential outcome will not be recognised and controls may not be sufficient to protect the worker. More details about hazard identification techniques are discussed in Chapter 3. Strategies for managing risk are included in Chapter 14.

Hazard and Risk

The terms hazard and risk are often used synonymously, although their meanings are quite separate. Hazard is defined in AS/NZS4360: 1999 as a source or situation with potential for harm in terms of human injury or ill health, damage to property, environment, or a combination of these. In other words, hazard relates to a possibility. Risk, on the other hand, is the likelihood or probability that the hazard will cause damage or harm. The degree or the magnitude of the risk is determined by the duration of exposure, most likely outcome from exposure and the frequency of exposure.

For instance, a bath containing hydrochloric acid (used for etching metal) may be hazardous but only presents a risk to workers if they are working nearby and could be exposed to the acid and sustain an injury.
Asbestos fibres, which are firmly embedded in a matrix such as asbestos-cement sheeting (found on roofs from the 1950s), can be hazardous. However, a risk will only exist if the fibres are released from the matrix, become airborne and are inhaled. This may occur if the roof is cleaned using a high-pressure water spray or if the roof is broken.

Hazard = potential that an event sequence will cause damage or harm
Risk = likelihood that an event sequence will cause damage or harm. The combination of frequency, duration and severity of exposure.

The concept of risk assessment lies core to Australia’s occupational health and safety legislative framework. This extends to occupational hygiene hazards with some States prescribing the conduct of mandatory risk assessments for specific hazards such as manual handling and chemicals. While risk per se can be assessed using a number of methods, it is important to identify the assumptions and limitations that go with the process. Quantitative risk assessments of occupational hygiene hazards generally involve measuring exposure and comparison against a scientifically validated benchmark. Consideration is made of the nature of the hazard, the cycle or pattern of exposure and knowledge about the acute and chronic health effects of the agent. Due to the complex issues associated with interpretation of data, these types of risk assessments are best performed by qualified and experienced occupational hygienists. Misinterpretation of exposure results is a serious issue with both legal ramifications for an employer managing risk and potentially compromising workers’ health.

Qualitative risk assessment is made by evaluating the three components of risk and the most likely event sequence. For instance, the frequency of exposure may be judged as ‘rare’ or ‘occasional’. The duration of exposure may range from ‘constant’ to ‘less than once each day’. Severity of outcome can be measured by magnitude, such as ‘death’ or ‘minor injuries’.

Risk management as a profession incorporates many sources of loss. In order for an organisation to manage the potential losses, a philosophy of recognition, evaluation and control is promoted. However, depending upon a person’s experiences and beliefs, they may approach the task in different ways. This could be due to their perception of risk.

**RISK PERCEPTION**

The final decision about the level of risk in the workplace will vary depending upon perceptions. Risk perception is an individual’s interpretation of the level of risk associated with an event and their tolerance to this risk. Risk perception will be discussed further in Chapter 14 and it is influenced by factors such as:

- **self-control over the risk versus imposed risk**
- **natural versus human-made risk**
- **familiarity with the risk**
- **understanding of the effects of exposure to the risk**
- **financial or other gain to be made from exposure to the risk**
- **cultural norms, beliefs and values**
- **society’s acceptance of risks.**

Some industries such as underground coalmining traditionally provided workers with a financial incentive to work in particularly high-risk places. Extra payment was given for working in noisy or dusty environments. Even today, with ever-improving standards of health and safety at work, it is clear that a worker’s perception of risk can be influenced by the factors identified above. Risks may be
tolerated because of the perceived advantages. While the risk is not unacceptable, a compromise may be reached where the positive aspects are accepted as outweighing the negatives.

STATES OF MATTER

In the workplace, hazards can exist in a number of forms. It is also important to note that a substance’s state of matter can change during a process or naturally. States of matter refers to the physical and chemical composition and arrangement of atoms (the building blocks of all objects). It can be described in terms of a microscopic or macroscopic aspect. A microscopic outline refers to the motion of all the atoms of molecules making up the substance. The macroscopic description of matter gives us a more practical application and allows us to look at the effect of the substance’s pressure, temperature and volume.

Atoms are the smallest form of matter, and contain protons, neutrons and electrons. When a number of atoms combine together, a molecule is formed. For instance, 1 atom of sodium (Na\(^+\)) could combine with 1 atom of chlorine (Cl\(^-\)) to form 1 molecule of salt (NaCl). These atoms combine by exerting attractive forces on each other. However, if the molecules move too close, the force becomes repulsive as the outer electrons electrically repulse each other. Thus the atoms must maintain a minimum distance from each other to maintain the molecules in a more or less fixed position — a crystal lattice.

In a solid, the atoms or molecules are nearly locked into a position with little movement, vibrating around this position. In a liquid, the forces between the atoms or molecules are weaker, allowing them to move more rapidly and roll over each other. With a gas, the atoms or molecules move so freely and collide into one another that the force of attraction is not strong enough to keep them close together, and they fill any space and move in all directions.

Atoms and molecules also have an atomic or molecular mass, respectively. This refers to the relative mass of the atoms and molecules,

**Case study 2: Risk perception**

A worker at a construction site is conscious of the high levels of noise at the workplace. He stringently observes signage requiring that hearing protection devices be worn in designated areas and coaches other people that visit the site without wearing earplugs. At the end of a busy week, he unwinds at his local club. After leaving the club he notices that his hearing feels a little ‘dull’ and experiences a buzzing sound in his ears that lasts for several hours. While he acknowledges that the noise levels at the club may be high, he is willing to accept the exposure as it is his choice and he believes that loud music is the norm at a club.
compared with an ordinary carbon atom ($^{12}\text{C}$), which is given a value of exactly 12.000 atomic mass units (u). The atomic mass of atoms can be found in the periodic table of elements. The periodic table is shown at the front of this book. Some examples of atomic masses are shown in Table 1.1.

Table 1.1 Examples of atomic masses

<table>
<thead>
<tr>
<th>Atomic number</th>
<th>Element</th>
<th>Atomic mass (u)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydrogen</td>
<td>1.0080</td>
</tr>
<tr>
<td>2</td>
<td>Helium</td>
<td>4.0026</td>
</tr>
<tr>
<td>3</td>
<td>Lithium</td>
<td>6.94</td>
</tr>
<tr>
<td>4</td>
<td>Beryllium</td>
<td>9.0122</td>
</tr>
<tr>
<td>5</td>
<td>Boron</td>
<td>10.81</td>
</tr>
<tr>
<td>6</td>
<td>Carbon</td>
<td>12.011</td>
</tr>
<tr>
<td>7</td>
<td>Nitrogen</td>
<td>14.0067</td>
</tr>
<tr>
<td>8</td>
<td>Oxygen</td>
<td>15.9994</td>
</tr>
<tr>
<td>9</td>
<td>Fluorine</td>
<td>18.9984</td>
</tr>
</tbody>
</table>

Example 1.1

What is the molecular mass of 1 molecule of zinc oxide?

Answer:

One molecule of zinc oxide consists of 1 zinc (Zn) atom and one oxygen (O) atom, forming ZnO. The atomic mass of zinc is 65.38 u and the atomic mass of oxygen is 16.00 u. The molecular mass of 1 molecule of zinc oxide is therefore 65.38 + 16.00, or 81.38 u.

The three main states of matter are:

- **solid**
- **gas**
- **liquid**.

Temperature, pressure and volume can also change the properties of matter. For instance, a steel beam is longer when heated, concrete expands and contracts according to temperature, and water can change from solid to liquid as temperature increases.

From an occupational hygiene perspective, the main categories of substances that we deal with are:

- **dusts**
- **fumes**
- **smoke**
- **aerosols**
- **mists**
- **gases**
- **vapours**.

**Dusts**

Dusts or particulate are solid matter, whose chemical composition and size vary. A solid can be a pure substance such as gold or it can be a compound such as lead oxide (PbO) or a combination of molecules. Solids maintain a fixed shape and fixed size, even when a large force is applied to the solid.
Some examples of dusts include:

- **wood dust**
- **pesticide and herbicide dust**
- **alkali dust** (e.g. potassium permanganate, $(\text{KMnO}_4)$, used in water treatment plants)
- **crystalline silica** $(\text{SiO}_2)$ from sandstone or granite and often found in coal seams.

Fume is also solid matter but the matter is heated and is finely divided. Fume is often visible to the naked eye and is typically generated from heating metal (Figure 1.2).

**Smoke**

Smoke is a complex mixture of particulate, vapour and gas. The particulate arises from combustion of solid material and gases such as:

- **carbon monoxide** $(\text{CO})$
- **oxides of nitrogen** $(\text{NO}_x)$
- **carbon dioxide** $(\text{CO}_2)$.

The composition of the smoke mixture is constantly changing between the particulate, vapour and gaseous form.

**Aerosols**

Aerosols and mists refer to liquid droplets that are suspended in the air. A simplified example of mist is fog. Fog occurs where warm and cold air meet and where the warm moist air blows over a cold surface. This causes condensation of dissolved water in air to form. Some examples of aerosols and mists found in the workplace include mists from the use of acid-filled vessels for cleaning metals before being electroplated and mists from pressure-pack cleaning aids.

**Gases**

Gases consist of a loose matrix of atoms or molecules that move randomly within a space. Some examples of gases include:

- **oxygen** $(\text{O}_2)$
- **nitrogen** $(\text{N}_2)$
- **methane** $(\text{CH}_4)$
- **helium** $(\text{He})$.

Since the atoms or molecules move and collide in a space, they can be affected by temperature, pressure and volume. This is especially important when assessing the effect of gases entering confined spaces or the impact of an increase in temperature within a workplace. It has been found that a particular volume of a gas is inversely proportional to the pressure applied, where the temperature remains constant. This relationship is known as Boyle’s Law and is shown in Equation 1.1.
Equation 1.1

\[ V = \frac{1}{P} \text{ (constant } T \text{)} \]

Therefore, if the pressure on a gas is doubled, its volume is reduced to half the original volume. Temperature will also affect the volume of a gas. Jacques Charles (1746–1823) described the quantitative relationship between volume (\( V \)) and temperature (\( T \)) more than a hundred years after Robert Boyle’s discovery. Charles identified that the volume of a gas increases at an almost constant rate, when the pressure is not high and is kept constant, as the temperature increases.

However, all gases liquefy at low temperatures. This means that the relationship between temperature and pressure only exists to the lowest temperature that gas can exist at. This value has been measured as \(-273.15^\circ\text{C}\), and is known as the absolute zero of temperature. Absolute zero forms the basis of the Kelvin (K) scale, which specifies temperature as degrees Kelvin (K). To convert between degrees Kelvin and degrees Celsius, it is simply a matter of adding 273 to the Celsius value. In other words, 273 K is equal to 0°C.

Therefore, if the temperature of an ideal gas is increased, the pressure and volume will also increase (Equation 1.2).

Equation 1.2

\[ T \propto V \text{ (constant } P \text{)} \]

Imagine a balloon filled with air and then left to sit in a car during a hot day. What happens? The balloon walls will stretch as the pressure caused by the increasing temperature rises. This then results in increasing volume and eventually the balloon walls will stretch no further and it explodes.

Another law of gas shows the relationship between pressure and temperature, and is known as Gay-Lussac’s law. In this law (Equation 1.3) the pressure of gas is directly proportional to the absolute temperature, where the gas is at a constant volume.

Equation 1.3

\[ P \propto T \text{ (constant } V \text{)} \]

An example of this law in application is a closed tin of highly volatile hazardous substance which may explode when left in the sun due to an increase in the gas pressure inside.

The relationship between these variables is described as the ideal gas law and is shown as Equation 1.4. This relationship shows that the combination of pressure (\( P \)) and volume (\( V \)) is proportional to temperature (\( T \)) and the number of moles of gas (\( n \)), given a constant of proportionality (\( R \)). \( R \) is known as the universal gas constant (8.315 J.mol\(^{-1}\).K\(^{-1}\)) and is constant for all gases. A mole (mol) is the amount of a substance that contains as many atoms or molecules as there are in 0.0012 kg of carbon-12 (\( u = 12 \)). In other words, 1 mole is the number of grams that are numerically equal to the molecular mass of the substance. For instance, 1 mol nitrogen (\( N_2 \)) has a mass of 0.028 kg.

Equation 1.4

\[ PV = nRT \]

\begin{align*}
\text{Where:} & \\
P & \text{ is pressure (N.m}^{-2}\text{)} \\
V & \text{ is volume (m}^3\text{)} \\
T & \text{ is temperature (K)} \\
n & \text{ is number of moles (mol) of gas} \\
R & \text{ is universal gas constant (8.315 J.mol}^{-1}\text{.K}^{-1}\text{)}
\end{align*}

One final point relates to the terms standard temperature and pressure (STP) and normal temperature and pressure (NTP). Most references define STP as standard conditions, which means a temperature of 273 K (0°C) and...
pressure of 1 atmosphere (101 325 N.m\(^{-2}\)). NTP refers to a temperature of 298 K (25°C) and pressure of 1 atmosphere.

**Vapours**

Vapours can best be explained as molecules or atoms that escape from the surface of a liquid. As liquid, molecules are attracted to one another by strong forces. However, the molecules in the upper section of the liquid may leave the liquid for a short time.

Usually, the attractive forces of the other molecules will draw the vagrant molecule back to the liquid surface, but if the molecule has enough energy it will escape the liquid and remain in the gas phase.

Workplace examples of vapours include water vapour and the evaporation of solvents. As more molecules leave the liquid surface, the volume of liquid decreases and the concentration of vapour increases. When the number of molecules leaving the liquid is equal to the number returning to the liquid (i.e. it is at equilibrium), the area is said to be saturated. The pressure of the vapour when it is saturated is called the saturated vapour pressure (vapour pressure). The International System of Units (SI) unit for measuring saturated vapour pressure is the Pascal (N.m\(^{-2}\)). The saturated vapour pressure of a liquid increases with temperature. This is especially important from an occupational hygiene perspective as liquids are often heated to increase the speed of a process or improve its efficiency. For instance, a chemist may dissolve a sample in warmed sulphuric acid (H\(_2\)SO\(_4\)) for a faster result. If the saturated vapour pressure of the liquid is raised enough to equal the external pressure, tiny bubbles form in the liquid. In other words, the liquid is changing from a liquid state to the gaseous state, or boiling has begun.

**Example 1.2**

1.0 mol nitrogen (N\(_2\)) is being held at STP. What is its volume, if it behaves as an ideal gas?

Answer:

\[
V = \frac{nRT}{P} = \frac{(1.0 \text{ mol}) \cdot (8.315 \text{ J.mol}^{-1}.\text{K}^{-1}) \cdot (273 \text{ K})}{101 325 \text{ N.m}^{-2}} = 22.4 \times 10^{-3} \text{ m}^3
\]

Since there are 1000 litres (L) in 1 cubic metre (m\(^3\)), 1 mol nitrogen (or any gas) has a volume of 22.4 L at STP.

**TOXICOLOGY**

The word toxicology is derived from the terms toxic, meaning ‘a poison’ and ology, meaning ‘the study of’. In studying poisons, we are concerned with the adverse effects that they can exhibit on living cells and the human body. In fundamental terms, all substances are potentially poisonous or toxic.

It was Paracelsus (1493–1541) who first documented this, noting that it was the dose that determined the toxicity of a substance.

All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy.

When we are attempting to manage the risk associated with occupational hygiene hazards, it is very important that the mechanism of the effect is known, as well as the probability that it will occur. This begins by identifying where the substance or agent enters the body. The movement and metabolism of the substance through the body must also be known to determine the most likely response. Our aim is to reduce exposure to a level that is as low as reasonably achievable (ALARA).
A substance will only cause an effect if it comes into contact with the human body. The main ways this can occur are through:

- **inhalation of the substance**
- **absorption through the skin**
- **absorption through mucous membranes**
- **ingestion through the gastrointestinal tract.**

These are called the routes of entry (Figure 1.3).

**Inhalation**

Inhalation of a substance is the most common way for it to enter the body. This airborne substance may be a gas, vapour, dust, mist, fume or aerosol. At rest, a healthy person will breathe about 6 L of air each minute. Work requiring a high metabolic energy expenditure such as shovelling, pushing a wheelbarrow or lifting objects may increase the flow up to 150 L per minute. Even wearing respiratory protection such as air purifying respirators will increase the depth of breathing as air must be drawn through the filtering material.

**Absorption**

Absorption is the second most frequent route of entry of substances into the body. The skin protects against external factors such as the sun, heat, cold, bacteria and chemicals; however, some of the following chemicals can penetrate the skin:

- **fat- or lipid-soluble substances**
- **oleoresins of some poisonous plants, such as poison ivy**
- **organic solvents, such as acetone, toluene and benzene**
- **salts of heavy metals, for instance, mercury.**

Acids and alkalis may burn the skin. Sensitising agents such as isocyanates found in polyurethane manufacture and some paints can cause a reddening or irritation to the skin. Non-ionising radiation such as ultraviolet (UV) radiation from high-energy lamps and infrared radiation from the sun can burn the skin. Sharp objects and needles can penetrate the physical barrier of the skin and inject substances directly into the body. Broken or damaged skin provides an easy passage for substances to enter the body.

Absorption of substances may also occur through the mucous membranes of the nose, throat and eyes. This is particularly true for water-soluble gases such as formaldehyde used in histology laboratories (as formalin) for...
fixing specimens and as a glue or resin component.

**Ingestion**

Ingestion is the least common route of entry and can occur by substandard personal hygiene or by eating/drinking an unknown substance. Failing to wash hands, eating or smoking after handling a substance can leave a residue on the hands that can then be accidentally ingested.

Another more insidious form of ingestion occurs because of the normal clearance mechanism of the lungs. The lining of the trachea is constructed from finger-like projections called cilia, which are covered in a mucous membrane. The mucous collects foreign particles before they enter the lungs. As the contaminants are moved along the mucociliary escalator for elimination, they are swallowed and removed through the digestive system. This is one reason why asbestos workers have a higher than normal incidence of stomach cancer.

**DISTRIBUTION, METABOLISM AND EXCRETION**

When substances enter the body, they are distributed and are subject to a number of biochemical reactions. These chemical reactions are known collectively as ‘metabolism’. Metabolism can be anabolic or catabolic. Anabolic (synthetic) metabolic processes form larger molecules or structures from smaller ones. Catabolism is a degradative process where complex structures are broken down into simple ones. During these processes, the substances can be transformed and an entirely different substance may be excreted from the body.

The usual course of a substance is as follows: uptake–distribution–metabolism–excretion.

We have already discussed the three major routes of entry — inhalation, absorption and ingestion. Inhalation is the most significant mechanism for uptake of gases, vapours, mists, fume and dust. Substances that are fat- or water-soluble can be easily absorbed through the skin and ingestion is generally not a major route of entry.

Once a substance has entered the body, it can show an effect in a number of ways. The effect may be localised where the damage or ill health occurs at the site of initial contact. For instance, exposure to sulphuric acid can burn the skin and exposure to hexavalent chromium (CrVI) salts can cause dermatitis and skin ulcers.

Another substance, however, may cause a systemic effect where other organs or systems of the body are affected. Many substances are distributed via the bloodstream. The ability of a substance to move throughout the body is influenced by its chemical/physical properties and its ability to cross membrane barriers. Cells in the human body are surrounded by a membrane consisting of two protein layers with a lipid (fat) layer in between. There are also small pores with a diameter of 2–4 angstroms (Å) traversing the membrane. (An angstrom is $10^{-10}$ metres.)

This means that there are three ways a substance can cross a membrane:

- **If a substance is lipid-soluble, it can simply diffuse through the membrane.** A substance that is small enough can pass through the pores. This is called passive diffusion.
- **A substance may bind with a specialised carrier molecule to carry the substance through the lipid layer.** This is known as facilitated diffusion.
- **The substance can be actively transported against a concentration gradient.** This requires energy input, and is known as active transport.
In general, molecules that are fat-soluble can cross membranes quicker and easier than those that are water-soluble. Once a substance enters a compartment of the body, it can exert an effect in that location or even move to other areas of the body. The main organs that are susceptible to storage of chemicals include:

- fatty tissues
- nerve cells
- bone and bone marrow
- liver
- kidneys
- thyroid.

For instance, inhalation of lead oxide (PbO) fume can result in distribution throughout the body and then symptoms of exposure to lead can appear in the bones, blood, reproductive system and kidneys. If the substance reaches a site in the body that has a high affinity for it, the substance can accumulate and remain in this area. These sites are known as storage depots. Some typical examples of toxic substances and their storage depots are shown in Table 1.2.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Storage depot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>Haemoglobin (in red blood cells)</td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>Fat</td>
</tr>
<tr>
<td>Chlorinated pesticides (eg. DDT)</td>
<td>Fat</td>
</tr>
<tr>
<td>Lead</td>
<td>Bone</td>
</tr>
</tbody>
</table>

In some cases, substances are taken into the body in a particular form and then removed in a different form. The reason for this disparity is the role of metabolism taking over, causing a chemical biotransformation of the substance. Biotransformation can be advantageous or hazardous, in terms of exposure. For instance, benzene (C₆H₆), a toxic aromatic hydrocarbon, is used as an industrial solvent. In the body, the liver oxidises it to phenol which then combines with glutathione to form non-toxic mercapturic acid metabolites. In contrast, methanol is biotransformed to formaldehyde, a carcinogen.

Within the cells there are several ways that substances are metabolised and biotransformed. The most significant mechanism uses enzymes (chiefly in the liver) to detoxify the substance in two phases (Figure 1.4).

Phase I involves forming a more reactive metabolite that is suitable for the conjugate enzymes in Phase II metabolism. Phase II metabolism turns the ‘reactive metabolite’ into excretable compounds by conjugating (joining) with enzymes. Ideally, the reactive metabolite will follow the correct pathway for this to occur; however, if the pathway is saturated, the reactive metabolite may accumulate or an alternative pathway may be used. If either of these options occurs, toxic effects can result.

**DOSE**

The concept of dose is paramount for occupational hygiene and risk management. Dose refers to the amount of a substance to which we are exposed, and is a combination of the concentration of exposure and duration of exposure.

Dose = concentration x duration of exposure

Dose depends on the following factors:

- **rate of absorption** (depending on the route of entry)
- **blood perfusion rate** to the organ under consideration
- **rate of passage** of the chemical (and its metabolites) across the cell membrane
• **volume of distribution** for the chemical
• **rate of bio-transformation** of the chemical
• **degree of binding** of the chemical (and its metabolites) to tissues and plasma proteins
• **rate of excretion** of the chemical (and its metabolites).

Generally, an increase in dose will result in an increase in response. This is known as the dose–response relationship. The relationship may be linear, where the dose is proportional to the response, but mostly the relationship has a sigmoid or curved shape as shown in Figure 1.5.

Notice that the curve does not cross the Y-axis (representing response). This means that exposure at a particular dose may not lead to a response and indicates the existence of a dose threshold. A dose threshold assumes that the human body is able to cope with the exposure without effect. The curve then rises linearly, indicating that the dose and response are proportional to one another, before plateauing out to a peak response, which is not affected by increasing the dose and is known as a ceiling level.

These dose–response relationships are used in toxicology to estimate health effects from exposure to particular concentrations of substances over time. Scientists carrying out experimental toxicology use test animals (e.g. rats, mice, rabbits) and expose them to particular toxic substances, via alternative routes of entry, for different durations. Exposure is usually divided into the following four categories:

• **acute**
• **sub-acute**
• **sub-chronic**
• **chronic**.

From these tests, the toxicologist can obtain information about the potency of the
substance. The lethal dose (LD) gives a measure of the substance’s potency, and is often reported as the LD₅₀. This is the dose that is lethal to 50 per cent of a population. Other toxicological effects which can be gauged may be the:

- **LC₅₀** or the concentration of substance that is lethal to 50 per cent of the population
- **LD₅₀** which refers to the lowest dose found to be lethal in the test animals
- **LD₃₅** which is the highest dose found to be lethal in the test animals.

The difference between the LD₅₀ and LD₃₅ can be best described by individual susceptibility (Figure 1.6).

A person may show a high response to a particular dose of substance. This may be due to their genetic predisposition or from an immunological response known as hypersensitivity. Hypersensitivity is discussed in more detail in Chapter 2.

_Hyposensitivity_ reflects an unusually low response to a dose of substance. This may be due to an individual developing a tolerance over a period of exposures (which can be best explained as the dose–response curve shifting to the right) or as tachyphylaxis, where the resistance occurs rapidly.

**CARCINOGENICITY**

Carcinogenic substances are those which are known to cause cancer (an uncontrollable division and multiplication of cells). When this occurs, an abnormal number of cells (a neoplasm) forms. If the cells grow slowly and remain localised, they are known as benign neoplasms. Cancerous cells that grow rapidly and can invade surrounding cells and break away from the main mass to cause secondary growths in other areas of the body are called metastases.

In the workplace, there are many substances and agents that can act as cancer-causers (carcinogens). The common characteristic of these agents is their ability to change the genetic material in the nucleus of the cells (deoxyribonucleic acid or DNA). This does not mean that exposure to a substance or agent will automatically cause cancer! Some carcinogens will not have an opportunity to damage the body’s cells as they are neutralised through the immune system or enzymes. The process of changing a normal cell to a cancer cell is often incomplete.
The International Agency for Research on Cancer (IARC) classifies cancer using the following levels:

- **Group 1** — the agent is carcinogenic to humans
- **Group 2(a)** — the agent is probably carcinogenic to humans; there is limited evidence in humans but sufficient evidence in animals to support this classification
- **Group 2(b)** — the agent is possibly carcinogenic to humans but there is limited evidence available only
- **Group 3** — the agent is not classifiable as to its carcinogenicity to humans; agents placed in this group do not fall into any other category
- **Group 4** — the agent is probably not carcinogenic to humans; the evidence suggests a lack of carcinogenicity in humans and experimental animals.

The Internet address for the IARC website is: www.iarc.fr

Some examples of occupational carcinogens and their target organs are shown in Table 1.3.

### Table 1.3 Occupational carcinogens

<table>
<thead>
<tr>
<th>Carcinogen</th>
<th>Target organ</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOCA (4,4’-methylenebis (2-chloronaniline)</td>
<td>Bladder</td>
</tr>
<tr>
<td>Benzene</td>
<td>Bone marrow (leukaemia)</td>
</tr>
<tr>
<td>Asbestos</td>
<td>Lung</td>
</tr>
<tr>
<td>Pitch, tar and oil (polycyclic aromatic hydrocarbons)</td>
<td>Skin</td>
</tr>
<tr>
<td>Vinyl chloride monomer</td>
<td>Liver</td>
</tr>
</tbody>
</table>

**Mutagens and teratogens**

A mutation refers to a change in the genetic material found in cells. This change is irreversible and hereditary. The nucleus of a generalised cell contains matched chromosomes that contain DNA. DNA is a long, double-stranded chain of structural units (nucleotides) consisting of the following bases:
• adenine (A)
• thymine (T)
• guanine (G)
• cytosine (C).

DNA can be best described as a ladder, where the rungs are two joined bases and the uprights of the ladder are alternating sugar and phosphate molecules (Figure 1.7). The bases are joined together by a hydrogen bond. Bonding of the bases only ever occurs as A with T, and G with C. The whole molecule is then coiled into a spiral, called a double helix.

Teratogens cause mutations to the somatic cells of a developing embryo. If the foetus survives to birth, they may suffer from physical, behavioural and/or intellectual impairments.

One of the pertinent factors that differentiates occupational hygiene hazards from safety hazards is the period between exposure and the onset of ill-health symptoms. This is known as the latency period and relates to ‘when’ a substance will cause an effect. Chronic effects are long lasting and may be permanent (although not necessarily). Some examples of chronic exposure are:

- **pneumoconiosis (‘dusty lungs’) from exposure to coaldust**
- **silicosis after exposure to quartz dust**
• manganese dust or fume exposure, which may damage the central nervous system
• asbestosis and mesothelioma after exposure to asbestos.

Acute health effects occur during or soon after exposure, and last for a short period of time. Some examples of acute effects are:

• lacrimation (tearing) of the eye and irritation the respiratory tract from exposure to and inhalation of chlorine gas (Cl₂)
• burns of the skin from a spill of strong acid or alkali
• respiratory sensitisation caused by ozone (O₃) from photocopiers or the generation of a welding arc.

The effects of acute and chronic exposures are shown in Figure 1.8.

An acute dose results in the rapid accumulation of the substance over a relatively short period of time. A chronic dose occurs over a longer time frame and can be in two forms, depending on whether the substance is metabolised or excreted or if it accumulates and is stored.

If no elimination or excretion occurs, the accumulated dose will be additive. But, if the substance is partially metabolised or excreted, the accumulated dose will rise and fall — accumulating more slowly.

**NATIONAL EXPOSURE STANDARDS**

National exposure standards (NES) are used to assess the risk of exposure. In Australia, the National Occupational Health and Safety Commission (NOHSC) publishes this information in *Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment*. This publication can be purchased from the Australian Government Publishing Service and some limited information can be found on the NOHSC website.

The Internet address for the NOHSC website is:
www.nohsc.gov.au

The NES are part of the NOHSC’s declared package of standards and codes of practice that, in conjunction with guidance materials,
comprises the National Hazardous Substances Regulatory Package. NOHSC refers to the package as a blueprint for legislative control of hazardous substances. All Australian States and Territories have given legislative effect to the package by incorporating the principles into their respective hazardous substance legislation.

NES are defined as airborne concentrations of individual chemical substances that should not harm or impair health or cause undue discomfort to nearly all workers, according to current knowledge. They are also understood to guard against narcosis or irritation, which could lead to industrial accidents.

Many of the adopted exposure standards used in Australia have been obtained from overseas. In recent years, NOHSC has endeavoured to address the lag between Australian exposure standards and those adopted by comparable overseas occupational health and safety agencies. Its approach has been to expedite the review of substances where the UK Health and Safety Executive (HSE) occupational exposure limits (OEL) are lower than Australia's or where Australia has yet to set an NES. The reviews are undertaken in batches. The process begins with the selection of the substances by an NOHSC technical committee, followed by a call for public comment. A regulatory impact statement (RIS) accompanies final recommendations for the change to the NES. The RIS identifies whether the proposed action would reduce adverse health outcomes from exposure to the substance and would enable industry, workers and the community to align with international practice in terms of exposure control and the related flow of benefits to the worker and the community. Costs and other benefits are also considered.

Many of the adopted NES have also been sourced from the American Conference of Governmental Industrial Hygienists (ACGIH) list of exposure standards. This publication provides recommendations and guidelines for more than 700 chemical substances, physical agents and biological exposure determinants. Most developed countries have their own exposure standards, although these are known by different names. For instance, in the US exposure standards are called threshold limit values (TLV) and in the UK they are known as the occupational exposure limits (OEL).

In the US, the National Institute of Occupational Safety and Health (NIOSH) expresses TLV as recommended exposure limits (REL). REL are time-weighted average concentrations for up to a ten-hour work shift during a 40-hour working week. Short-term exposure limits are also designated. A ceiling REL is designated for certain substances and should not be exceeded at any time. Also in the US, the Occupational Safety and Health Authority (OSHA) has recommended permissible exposure limits (PEL). PEL are time-weighted average concentrations that must not be exceeded during any eight-hour work shift of a 40-hour working week.

It is interesting to note that in different countries some exposure standards for the same substance can differ. The reasons for this can be different testing regimes or perception of risk and influence by industry and stakeholders. Although we accept that exposure to chemical substances must be kept ALARA (as low as reasonably achievable), industry may lobby regulatory authorities under the auspices that reduction of an exposure below a low exposure standard may not be achievable. This may also be a reason that exposure standards are not static but can increase or lower over time. As our knowledge about substances changes over time, exposure standards may alter to reflect the risk associated with exposure.

Exposure standards are not dividing lines between ‘safe’ and ‘unsafe’ but can be applied to assess the risk to exposed workers and assist in deciding on control measures to minimise exposure. Because each person may react differently if exposed to a substance, some
people may show symptoms of ill health even if exposed to less than the occupational exposure standard. In other words, some workers may be more susceptible than others. Unfortunately, the occupational exposure standards do not account for this individualism.

Similarly, exposure standards have been developed on the assumption of a normal workday. But what is ‘normal’? Each day exposure may differ, depending on the production rate, use of the substance, climatic conditions and intensity of work. Workers who breathe through their mouth, rather than their nose, may be exposed to higher concentrations of contaminants. The lung ventilation rate may also increase if:

- the nature of work is heavy
- the work requires a high metabolic work rate
- the conditions are hot or humid
- the work is performed at altitude.

These are a few reasons why the application of exposure standards should be used carefully in assessing workers’ risk to substances. Additionally, as we have already established, exposure standards are defined as airborne concentrations of chemical substances; and the exposure standards are only valid where significant skin absorption cannot occur and they consider absorption through inhalation only.

**SAMPLING AND MEASUREMENT**

When measuring the actual concentration, it is important that the measurement is indicative of a worker’s exposure to the substance. Risk assessments require an estimation of the likelihood of exposure that will lead to an adverse effect. Therefore, the substance is measured in the ‘breathing zone’ of the worker (Figure 1.9).

The breathing zone is defined as a hemisphere with a radius of 300 mm in front of the face of the worker and drawn from a line bisecting the ears. The airborne concentration of the contaminant under investigation must be measured in this region for the NES to be applied. This is known as ‘occupational sampling’. ‘Para-occupational’ or ‘static’ sampling occurs where the concentration of an agent is not measured in the breathing zone but at a workstation or workplace.

Strictly speaking, para-occupational or static samples should not be compared directly with the NES, since the measurement may not be indicative of the worker’s actual exposure, and hence risk. Para-occupational sampling is best used to assess control measures which have been implemented or where environmental monitoring of fugitive emissions to the air may be required. The latter point about environmental monitoring (for instance, for evaluation of air quality or non-occupational exposure) is not discussed in this text but environmental science texts will provide further information.

Many substances have not been assigned NES. The absence of an exposure standard should not lead to the assumption that the substance is safe or that exposure should not be reduced to ALARA. If there is insufficient information about the health effects of substances, the substance is under review or the use of the substance is minimal, an exposure standard may not be specified. In this case, it is always wise to minimise exposure since our ‘current knowledge’ can change in the near future.

**TYPES OF NATIONAL EXPOSURE STANDARDS**

National exposure standards can be expressed in three ways to reflect the duration of exposure. The typical exposure standard is expressed as the time-weighted average (TWA)
concentration of a substance for an eight-hour working day and a five-day working week. Provision is also made for short-term exposures above the TWA for exposure to some substances, as long as there is an equivalent excursion below the TWA. However, the application of these short-term excursions should all be considered when assessing a worker’s exposure to a substance.

**Exposure standard — time-weighted average**

The TWA refers to the average airborne concentration of a substance during an eight-hour working day for a five-day working week. In other words, it integrates peaks and troughs of exposure during an entire day. During this eight-hour averaging period exposures above the TWA are permitted (peaks on the graph), provided an equivalent reduction in exposure occurs (troughs on the graph). This is very important when considering a worker’s exposure to a substance on extended shifts, such as shifts of ten or twelve hours. The TWA is based on an exposure-free time of sixteen hours between shifts to allow metabolism and excretion of substances before re-exposure. The TWA should not be applied in situations of extended shifts without modification, as the time between exposure and recovery has been reduced.

**Exposure standard — short-term exposure limit**

With some substances, a short-term exposure limit (STEL) has been specified to minimise the number and duration of excursions. Exposure to some substances can cause uncomfortable irritation; narcosis or tissue change from short-term exposure, as well as long-term health effects. Some examples of such substances include:

- ammonia from large refrigerating plants
- zinc oxide fume from welding galvanised steel

Figure 1.9  The breathing zone

concentration of a substance for an eight-hour working day and a five-day working week. Provision is also made for short-term exposures above the TWA for exposure to some substances, as long as there is an equivalent excursion below the TWA. However, the application of these short-term excursions should be carefully reviewed to ensure the effects of acute exposure do not place workers at an increased risk of ill health.

The Y-axis in Figure 1.10 is the TWA concentration and the curved line shows actual exposure for a worker. The graph shows that exposure varies during the shift, sometimes exceeding the TWA and at other times being well below the TWA. These excursions should all be considered when assessing a worker’s exposure to a substance.
STEL supplements the TWA of a substance; therefore, although such excursions may be allowed, the TWA must not be exceeded.

The STEL is expressed in the same manner as exposure standards and is averaged over a period of fifteen minutes. The STEL should not be exceeded at any time during the normal eight-hour work shift, and a maximum of four STEL excursions are permitted during the workday. At least 60 minutes of non-exposure should be given between successive exposures at the STEL concentration.

The NOHSC has suggested that a process is not considered to be under reasonable control if an individual STEL exceeds the TWA by five times, or if short-term exposures exceed the TWA three times for a total of 30 minutes in an eight-hour shift. However, the basis for this recommendation is not directly health-related and therefore caution should be exercised if using this guidance.

**Exposure standard — peak limitation**

A peak limitation may be allocated to some substances where it is not appropriate to average the airborne concentration over an eight-hour shift because of the substance’s irritancy or fast effect on the body. The peak limitation is expressed in the NES under the STEL column heading, and represents a maximum concentration that workers may be exposed to.

**UNITS OF MEASUREMENT**

In Australia, NES can be specified in a number of ways. The method of expression will depend upon the nature and physical composition of the contaminant. Gases and vapours are usually expressed as parts per million (ppm). This refers to the number of molecules of the substance per million air molecules. Since it is a volumetric value, it will not be affected by changes in temperature and pressure. Parts per
million can also be converted to a percentage in air. By comparing 1 ppm (1/1,000,000) with 1 per cent (1/100), the difference is 10,000. Therefore, 1 per cent is equal to 10,000 ppm, or 1 ppm is 0.0001 per cent.

**Example 1.3**

The normal concentration of oxygen (O₂) in air is 20.9%. A grain silo was found to contain 15.3% O₂. How many ppm of oxygen has been displaced?

**Answer:**
The percentage of oxygen lost from the space is 20.9% – 15.3%, or 5.6%. This is equal to 56,000 ppm (from):
- 1% → 10,000 ppm
- 5.6% → 56,000 ppm

The airborne concentration of gases, vapours and particulate can also be expressed gravimetrically (or by weight). The term used is milligrams per cubic metre of air (mg.m⁻³).

Temperature and pressure can affect these units and a conversion formula (shown as Equation 1.5) can be used to convert from ppm to mg.m⁻³.

**Equation 1.5**

\[ \text{mg.m}^{-3} = \frac{\text{MW} \times \text{ppm}}{22.4 \times \frac{T_1}{T_2}} \]

Where:
- MW is molecular weight
- \(T_1\) is 273 K
- \(T_2\) is (\(t\) + 273 K)
- ‘\(t\)’ is the actual temperature in Kelvin (K)

This formula assumes that the volume of an ideal gas is 24.4 L at normal pressure and temperature conditions. Example 1.4 shows the workings for this theory.

**Example 1.4**

Convert 5000 ppm of carbon dioxide (CO₂) to mg.m⁻³ at 50°C.

**Answer:**
\[
\begin{align*}
\text{mg.m}^{-3} &= \frac{\text{MW} \times \text{ppm}}{22.4 \times \frac{T_1}{T_2}} \\
&= \frac{44 \times 5000}{22.4 \times \frac{273}{323}} \\
&= 8301 \text{ mg.m}^{-3}
\end{align*}
\]

Notice that since the temperature is not at 25°C, the equation can be simply modified by multiplying its right side by \(\frac{T_1}{T_2}\), where \(T_1\) is 273 K and \(T_2\) is the actual temperature of the conditions. These values should be inserted in Kelvin, where 0°C is equal to 273 K and \(T_1\) is 298 K.

Fibre particles are expressed as fibres per millilitre of air (f.mL⁻¹). Some examples of the application of this style of measurement are asbestos and synthetic mineral fibre exposure.

**Extended shifts**

Many workplaces in Australia have moved toward extended shift schedules rather than the traditional eight-hour day, five-day working week. While the impetus is largely economical and is often supported by workers who perceive a shortened week with extended shifts to be advantageous, the application of current NES may be inappropriate. The TWA is based on an eight-hour exposure, followed by a sixteen-hour break from exposure. Where the recovery period is reduced (to fourteen or twelve hours), substances may accumulate in the body and place workers at risk of illness.

A number of models have been developed and can be applied where work shifts differ to the eight-hour shift. It is not necessary to adjust the peak limitation and STEL values since these are designed to minimise the risk associated with acute exposures. The TWA, however, needs to be adjusted. The following models can be used:
**Brief and Scala Model**

The NOHSC Exposure Standards Expert Working Group recommends the Brief and Scala Model be used for calculating adjustments to the exposure standards. This involves the number of hours worked each day and the exposure standard of the substance whose TWA is being adjusted. The limitation of this model is that it does not consider the metabolism and the toxic effect of the substance. The formula for the Brief and Scala Model is shown in Equation 1.6.

**Equation 1.6**

\[
\text{Adjusted exposure standard (TWA)} = \frac{8 \times (24 - h) \times \text{Exp Std}}{(16 \times h)}
\]

Where:
- \( h \) is hours worked each day
- TWA is time-weighted average

**Example 1.5**

A worker is exposed to n-hexane for a 12-hour shift. The 8-hour TWA for n-hexane is 20 ppm. Using the Brief and Scala Model, determine the adjusted exposure standard for a 12-hour shift.

**Answer:**

\[
\text{Adjusted TWA} = \frac{8 \times (24 - h) \times \text{TWA}}{(16 \times h)}
\]

\[
= \frac{8 \times (24 - 12) \times 20 \text{ ppm}}{(16 \times 12)}
\]

\[
= 10 \text{ ppm}
\]

**OSHA Model**

The OSHA Model is an American model which categorises air contaminants according to their toxic effects. Any adjustment to the exposure standard is based on the categorisation of the substance. It is not recommended for use in Australia as the exposure standards are based on US threshold limit values and that categorisation system is not currently used in Australia.

**Pharmaco-kinetic Model of Hickey and Reist**

The Pharmaco-kinetic Model of Hickey and Reist is a complex model that considers the metabolism, biotransformation and excretion of a substance. While it is theoretically more correct than the Brief and Scala or OSHA models because it considers the biological half-life of the substance, information about how night work or extended shifts affect metabolism and excretion of substances is not available to fully support its use. Therefore, the application of the Pharmaco-kinetic Model of Hickey and Reist should be limited to those who understand toxicology and the pharmaco-kinetics of the substance under consideration.

**Mixed exposure**

Australian NES are based on single ingredients. In most workplaces, it would be rare for a worker to be exposed to just one substance. We must then consider how the exposure standards can be applied where multiple exposures occur. The first questions in determining the effects of exposure to mixtures of substances are: where do the substances affect the body, and what is the mechanism of action?

A number of terms are used to describe the effects of exposure to multiple substances:
• independent
• additive
• synergistic
• potentiative
• antagonistic.

Independent effects

If the substances affect different organs of the body, or have different mechanisms of action, then exposure to each substance can be considered individually. For instance, a painter may sand a timber house before painting with a toluene-based paint. Since the wood dust affects the nose and upper respiratory tract and toluene affects the central nervous system, each independent exposure should be compared against the appropriate exposure standard. These are called independent effects.

Additive effects

A combination of agents affecting one organ or having the same mechanism of action is described as having an additive effect. To determine whether a worker is overexposed to two or more substances, the additive effect is calculated using the airborne concentration and the relevant exposure standard, as shown in Equation 1.7. If the combined amount is less than 1, the exposure standard for the mixture is not exceeded.

\[
\frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots + \frac{C_n}{L_n} \leq 1
\]

Where:
- \(C\) is the concentration of substance
- \(L\) is the national exposure standard

Example 1.6

A furniture restorer is exposed to 1.2 mg.m\(^{-3}\) of oak (hardwood) dust and 2.3 mg.m\(^{-3}\) of hoop pine (softwood) dust while sanding antique furniture. She sands the furniture using an orbital sander and then varnishes them using a 2-pack varnish containing toluene diisocyanate (TDI). Her exposure should be considered from two perspectives: wood dust exposure and isocyanate exposure.

Since wood dust affects the nasal cavity and upper respiratory system, the effects are additive. Isocyanates can cause sensitisation of the skin and respiratory system.

The additive effects of the dust would be: \(1.2/1 + 2.3/5 = 1.7\)

The exposure standard for the wood dust mixture is exceeded. Exposure to isocyanate vapour would be considered independently.

Synergistic effects

Multiple exposures sometimes cause a ‘more-than-additive’ effect. Synergism occurs where individual substances each have an effect but when combined produce a ‘more-than-additive’ effect. For instance, exposure to solvent vapour and excessive noise increases the risk of hearing loss.

Potentiative effects

Potentiation refers to the enhancement of a substance by a second agent that by itself would have no effect. The actual mechanism of these interactions is detailed and not fully understood; therefore, exposure should be kept ALARA.
Antagonistic effects

An antagonistic effect occurs when the effects of the two substances are less than the effect of each in isolation.

BIOLOGICAL EXPOSURE INDICES

Occupational hygienists frequently use airborne concentrations of substances compared with exposure standards to determine the level of risk to workers. This technique is widely accepted as the most useful in the workplace, as it is not invasive. The results can be compared with generally accepted exposure standards that are available for many chemicals. However, the application of exposure standards is limited in that they do not consider skin absorption or entry through other routes and the risk assessment is often generalised.

Biological monitoring measures the levels of a substance or its metabolites in the following bodily fluids and tissue:

- blood
- sweat
- urine
- faeces
- hair
- fat
- exhaled breath
- milk.

It is particularly useful in identifying a worker’s ‘actual’ exposure without generalising about the ‘typical’ worker. Everyone differs in his or her physiological make-up, size, fitness, nutrition, personal hygiene and habits. These characteristics may affect the uptake, metabolism and excretion of substances. Biological monitoring enables an individual assessment of exposure to be made.

Similar to the occupational exposure standards, the results of biological monitoring are compared with biological exposure indices (BEI). The main sources of BEI used in Australia are from the ACGIH ‘Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices 1996–1997’.

The Internet address for the ACGIH website is:
http://www.acgih.org

From a practical perspective, biological monitoring requires considerable tact and skill to collect an appropriate sample. Some samples must be collected at the beginning of a shift or within a restricted time window after exposure. Others require special methods of storage, preservation and transportation for analysis. Invasive techniques such as the collection of blood samples must be taken by an appropriately qualified health professional and the interpretation of results should be made by an occupational physician who is aware of the recommended range or level for action.

When collecting urine samples, the urine concentration can vary widely due to variations in fluid uptake or sweating. Collection from the workplace can be subject to error due to the timing of collection and incomplete bladder emptying. Urinary results should therefore be creatine-corrected in certain cases. The analytical laboratory should be consulted to assess whether this is necessary.

Some examples of substances which can be assessed through biological monitoring include:

- **MOCA** (used in production of plastics) through urine
- **antimony** (used in the production of alloys and flame retardants and in the glass industry) through urine
- **heavy metals** (such as arsenic and lead) through hair
- organochloride pesticides through fat assays and breast milk
- carbon monoxide through exhaled breath and blood
- styrene through its metabolite (urinary mandelic acid) at the end of a shift.

**EPIDEMIOLOGY**

The science of epidemiology is aimed at identifying the link between the cause and effect of diseases. Last (1995, p. 55) describes epidemiology as the ‘study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems’.

Workplaces provide an ideal opportunity to conduct epidemiological studies, as information is readily available about the workers, the type and nature of work and the controls that are in place at the workplace. Additionally, symptoms of exposure can be identified and actual exposure may even be measured.

Epidemiological studies can be categorised in the following ways:

- **descriptive**
- **experimental**
- **analytical**.

**Descriptive**

Descriptive (or observational) epidemiology investigates the occurrence of disease or other health effect in a particular population. Observations are made about the age, gender, race, occupation, socioeconomic status and geographic location of the population.

**Experimental**

Experimental epidemiology is a study where the conditions are under the investigator’s direct control. A selected population undergoes a specific trial or regimen and the outcome of exposure is compared with a control group. Ideally, the subjects in this style of study would be selected randomly.

While experimental epidemiology is useful in certain occupational hygiene risk management strategies, such as setting exposure standards, the identification of disease or ill health is usually conducted using analytical studies.

**Analytical**

Analytical epidemiology examines the association between an effect (e.g. occupational disease) and its cause. This involves identifying or measuring risk factors. In this style of study, individuals from the study population can be classified according to the absence or presence of specific disease, and according to attributes such as:

- age
- race
- gender
- other diseases
- genetic, biomechanic or physiological characteristics
- socioeconomic status
- occupation
- residence
- environment
- personal behaviour.

The three main types of analytical studies are:

- **cross-sectional**
- **cohort**
- **case-control**.

**Cross-sectional**

The cross-sectional or prevalence study looks at the relationship between disease and other variables of interest in a defined population at a particular point in time. The study is conducted by identifying the presence or
absence of disease and other variables in each member of the study population. The relationship between a variable and the disease can then be examined in terms of the prevalence of disease in sections of the population (defined according to the presence or absence of the variables) and the presence or absence of the variables in the diseased compared with the non-diseased.

**Cohort**

A cohort study (also known as concurrent, follow-up, incidence, longitudinal or prospective study) begins at a particular point and follows exposed (or potentially exposed) individuals into the future. Cohort studies are particularly expensive and time consuming, as a large number of participants are involved over a long period of time. The outcome from the study is a determination of the incidence rate or mortality rate in groups that differ in exposure levels.

**Case-control**

The case-control study (also known as retrospective, case referent or comparison study) compares a person who has the occupational disease of interest (the 'case') with a suitable group of individuals who do not have the disease (the 'control'). The control is matched with the case for similarities in age and gender but the control does not have the disease or condition of interest. From this, a suspected risk factor may be identified by comparing the exposure history of the case and the control.

**Measures of mortality**

Mortality (death) is an extreme and final outcome of exposure! While it may appear simple to measure mortality as a number, we need to consider mortality in the workplace as a rate. A rate refers to a defined occurrence in a particular time frame. For instance, a flow rate may be described as 500 L per minute. The occurrence is the flow (given as litres) and the time frame is 'each minute'.

A crude mortality rate refers to the actual observed mortality rate in a population under study. By convention, the crude mortality rate is taken as deaths per 1000 and is measured as the population at mid year. This does not take account of any confounders or factors that have influenced the mortality rate such as age, lifestyle, race or gender.

\[
\text{Crude mortality rate} = \frac{\text{all deaths in a calendar year}}{\text{population at mid year} \times 1000} = \frac{\text{deaths per 1000 people}}{}
\]

In order to take account of characteristics that affect mortality, a comparison needs to be made between the population being studied and the 'general' population. This is done by separating the effect of the confounding factor from the effect of the factor of interest and statistically adjusting to remove the effect of the confounder.

From an occupational hygiene point of view, the most frequent mortality rate we use is the standardised mortality rate (SMR). This measure is used to demonstrate the proportion of the overall mortality that can be attributed to a specific cause and is expressed as a percentage. This figure does NOT provide any information about the actual rate that was involved. Also, we should be aware of the limitations of using data, which may not clearly identify all work-caused illnesses and deaths.

\[
\text{Standardised mortality rate} = \frac{\text{deaths from a disease in a certain year}}{} = \frac{\text{total deaths in the population in the same year}}{100}
\]
Incidence and prevalence

Incidence and prevalence are used to measure the frequency of a disease or illness. Incidence means new. Prevalence means all. It therefore follows that an incidence rate measures the rate at which people without a specific disease or illness develop the disease, and prevalence rate measures the number of people in a population who have the disease or illness at any given point in time.

Incidence rate = number of new cases of disease or illness over a period of time/population at risk of disease or illness in time period

So, a change in the prevalence rate may not necessarily be due to the incidence rate only. For instance, if the incidence rate rises but the duration of the disease decreases, then the prevalence rate will decrease. Equally, a stable incidence rate and decrease in the duration of disease (by rapid recovery or rapid death) will lower the prevalence rate.

Prevalence rate = total cases of disease or illness at a given time/total population at risk at a given time

RISK FACTORS

We have already defined risk as the likelihood that an event sequence will cause damage or harm. That risk depends on the combination of:

- frequency
- duration
- severity of exposure.

With epidemiological studies we use the terms ‘relative risk’ (RR) and ‘attributable risk’ (AR) to measure the association between exposure to a factor and the risk of a particular outcome (damage or harm). These are defined as follows.

Relative risk = incidence rate among exposed/incidence rate among non-exposed

Attributable risk = incidence rate among exposed — incidence rate among non-exposed

Since occupational epidemiology is concerned with identifying the relationship between the causal factors and their effects at work, it is important that the risk factors are identified. The ratio of the risk of a disease or death for a worker exposed to the risk among the non-exposed is called the relative risk. The opposite of this is the odds ratio or relative odds. The odds ratio can be defined in a number of ways, depending upon the situation under consideration, but is essentially the cross-product of exposure and disease. It can be simply explained as the multiplication of the odds that a particular event will occur divided by the odds that it will not occur.

Example 1.7 shows the theory of odds ratio and Example 1.8 provides a hypothetical example of how to calculate the relative risk and odds ratio.

Example 1.7

Determine the exposure–odds ratio for the following scenario.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Exposed</th>
<th>Not exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>No disease</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Answer:
The odds ratio is the ratio of the odds in favour of exposure among the diseases (1 x 4) to the odds in favour of exposure among non-cases (2 x 3). This reduces to 2:3.
Example 1.8

Determine the relative risk (RR) and odds ratio for this example.

<table>
<thead>
<tr>
<th></th>
<th>Exposed</th>
<th>Not exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disease</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>No disease</td>
<td>c</td>
<td>d</td>
</tr>
</tbody>
</table>

Answer:

The relative risk is
\[
\frac{a}{a+b} / \frac{c}{c+d}
\]

The odds ratio is \(ad:bc\).

SUMMARY

Occupational hygiene combines the sciences and arts to identify, evaluate and control hazards that may impact on workers' health. These hazards can be broadly categorised as chemical, biological, physical and ergonomic. The objective of occupational hygiene is to minimise the risk associated with exposure to these agents. Risk can be thought of as the likelihood that an event sequence will occur and cause damage or harm. It is a combination of the frequency, duration and severity of exposure.

The term risk management can be applied to the field of occupational hygiene, although it also relates to other sources of loss in the workplace from the environment, occupational safety, workers' compensation and rehabilitation plus insurance. Risk management adopts a philosophy of recognising agents in the workplace, assessing the exposure or dose and rectifying the problems.
Chapter 1: Fundamentals of occupational hygiene and risk management

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Chapter 2

Working out the human body

The human body is a complex series of interacting systems that adapt to continual change and variation. If it were not for the ability of the human body to respond to such demands, exposure to even small amounts of foreign substances would cause ill health and disease. The practice of occupational health and hygiene identifies, evaluates and controls these risks to health at work.

Occupational hygiene hazards can be categorised under the following broad headings:

- **physical hazards** — noise, light, vibration, heat, cold, radiation
- **chemical hazards** — gases, vapours, dusts, fibres, mist, fumes, aerosols, fog
- **microbiological hazards** — viruses, fungi, algae, protozoan, bacteria
- **ergonomic hazards** — stress, violence, shift work, manual handling.

Work can be classed as heavy industrial, such as in a foundry, mine, assembly shop or construction site. It may also be classed as commercial or service oriented, such as in an office, retail store, hospital, hotel or school. Occupational hygiene hazards may exist at all of these workplaces although they may be difficult to identify. Some examples of occupational hygiene hazards that are not easily recognisable are:

- glutaraldehyde exposure when cleaning endoscopes used in a hospital theatre
- asbestos exposure when removing brake linings
- hydrogen sulphide (‘rotten egg’ gas) exposure when entering a sewer.

This chapter will build on Chapter 1 and show a link between the cause and effects of exposure to occupational hygiene hazards. It will also describe the structure and functions of the main systems of the body and various types of movements that the human body can perform.

### OUR BODILY SYSTEMS

There are several levels of structures within the human body. The lowest levels are atoms such as oxygen, carbon, hydrogen and calcium, which combine to form molecules such as proteins, carbohydrates, fats and vitamins. Molecules join to make cells and tissue is made from similar cells. Some examples of tissues are muscle, nerves and connective tissue. At the organ level, at least two different types of tissue form an individual structure (e.g. the heart, lungs, stomach and brain). Organs that work together closely to perform a specific function form a system. The highest level of organisation is the organism (human body);
this is the total of all structural levels working together (Figure 2.1).

Occupational hygiene hazards can affect any level of the body’s structure. For example, exposure to ionising radiation (e.g. alpha ($\alpha$) and beta ($\beta$) particles) can damage a cell’s genetic material, DNA, and mutate the cellular information. Organic solvents, particularly toluene and xylene (used in paint, varnishes, resins and glues), have a narcotic property and affect the central nervous system. Heavy metals such as lead and cadmium used as alloys damage the kidneys.

To fully appreciate the effects of exposure to occupational hygiene hazards, it is important that the function and features of the body’s systems are clearly understood. When a substance enters the body it may change or be transformed. For instance, toluene is absorbed mainly through the lung (a small amount is absorbed through the skin) and accumulates in the fatty organs. About 90 per cent of inhaled toluene is biotransformed, mostly to hippuric acid, and rapidly excreted after exposure has ceased. The metabolism of toluene in humans is shown below.

Toluene

\[
\begin{align*}
\text{toluene} & \rightarrow \text{benzyl alcohol} \\
\text{benzyl alcohol} & \rightarrow \text{benzaldehyde} \\
\text{benzaldehyde} & \rightarrow \text{benzoic acid + glucuronic acid} \\
\text{glucuronic acid} & \rightarrow \text{hippuric acid}
\end{align*}
\]

There are 12 systems in the body. These are the:

- **cardiovascular system** — heart and blood vessels
- **digestive system** — oral cavity, oesophagus, stomach, small intestine, large intestine, rectum and anus
- **endocrine system** — pancreas,
ovaries, testes and adrenal, thymus, thyroid, pituitary and pineal glands

- **immune system** — spleen, red bone marrow, lymph nodes and the thymus
- **integumentary system** — skin, nails and hair
- **lymphatic system** — lymphatic vessels and lymph nodes
- **muscular system** — skeletal muscle
- **nervous system** — brain, sensory receptors, spinal cord and nerves
- **reproductive system** — male (testes, penis) and female (ovaries, vagina, uterus)
- **respiratory system** — nasal cavity, pharynx, larynx, trachea, bronchus and lungs
- **skeletal system** — bones, joints and cartilage
- **urinary system** — kidney, ureters and urethra.

The characteristics of these systems will now be described to illustrate the relationship between their structure, function and the effect that exposure to occupational hygiene hazards can have.

**CARDIOVASCULAR SYSTEM**

As the name suggests, the cardiovascular system consists of the cardiac muscle (the heart) and vascular tissue (the veins, arteries and capillaries). The system is essentially a delivery service that can adapt the flow of blood to suit the changing needs of the body (Figure 2.2).

The heart has four chambers — the superior (upper) atria (or auricles) and the inferior ventricles. It is also divided into two sides — left and right. The left side of the heart functions by allowing blood to be received in the left atrium from a vessel called the pulmonary vein. This vein joins the lungs

![Figure 2.2 Transporting blood through the cardiovascular system](image-url)
to the left atrium and contains oxygenated blood.

Blood enters the atrium where it is held for a moment before passing through the bicuspid valve and into the left ventricle. The ventricles are the powerful part of the heart and pump blood into the body for circulation. Blood is ejected from the left ventricle into the aorta, the largest artery in the body.

Some substances, such as carbon disulphide (CS₂), a strong solvent used in chemistry laboratories or as a component in the manufacture of viscose rayon fibres, can damage the coronary arteries and increase the prevalence of ischaemic heart disease.

Arteries are vessels that carry blood away from the heart. However, this does not necessarily mean that they always carry oxygenated blood. The pulmonary artery transports deoxygenated blood from the body to the lungs. Arteries are divided into three main groups — elastic arteries, muscular arteries and arterioles. An example of an elastic artery is the aorta. It has a large, thick wall that can withstand the high-pressure blood being ejected from the left ventricle yet adjusts to a reduction in pressure when the heart is not contracting. Muscular arteries are smaller than elastic arteries and work as the distributors of blood throughout the body. Arterioles are the smallest of the arterial vessels with an inside diameter (known as the lumen) of less than 0.5 mm. Once blood has left the heart it will travel via the arteries to the arterioles and into a network of small blood vessels called capillaries.

As the blood passes through the capillary bed it unloads oxygen (and other substances) and collects carbon dioxide. The tiny capillaries then rejoin to form venules. The venules unite to form veins, which then take blood back to the heart. The structure of veins differs to that of arteries in a few ways. They have only a small muscular wall, a large lumen and are very thin. This allows large volumes of blood to be transported. Since much of the blood moved in veins occurs against gravity, they have valves to prevent blood from flowing backwards.

The blood is returned to the right atrium and right ventricle of the heart through the largest vein in the body, the vena cava. The vena cava is made up of its inferior component (which returns blood from body areas lower than the heart) and the superior vena cava (returning blood from areas above the heart). Some blood will also be returned to the heart by the coronary sinuses. These collect blood that has drained from the heart itself.

The blood then leaves the right ventricle through the pulmonary artery, on its way to the lungs to be oxygenated. This is called pulmonary circulation and is essentially the path that blood takes to be oxygenated before returning to the left atrium via the pulmonary vein for circulation to the body once again.

**DIGESTIVE SYSTEM**

The digestive system is divided up into two main groups: the alimentary canal and the accessory organs.

**Alimentary canal**

The alimentary canal or gastrointestinal tract is a continuous tube that begins below the oral cavity and terminates at the anus. Exposure to occupational hygiene hazards may occur through the digestive system, although it is the least likely route of entry. Exposure through ingestion can occur in several ways:

- accidental consumption of a substance
- transmission from the hands or tools to the mouth
- smoking with contaminated hands
- inhalation of a contaminant which is then removed via the mucociliary escalator to the oesophagus for swallowing.
As substances enter the mucosa-lined cavity of the mouth, mechanical digestion begins with the teeth and tongue. Saliva is secreted from salivary glands to begin the chemical breakdown of starchy foods. Very little absorption occurs in the mouth, although nitroglycerine (an explosive ingredient in dynamite, 20–40 per cent, with ethylene glycol dinitrate, 80–60 per cent) is known to be absorbed in this area. The substances then pass into the pharynx and into the oesophagus. The oesophagus is a passage that connects the mouth to the stomach. Muscles of the oesophagus help food to be moved along in a wave-like motion called peristalsis.

Once substances pass through the oesophagus they reach the stomach (the organ involved in the majority of mechanical and chemical digestion). The stomach breaks down proteins in the highly acidic environment. Some fat-soluble substances are also absorbed through the lining of the stomach wall. The creamy mixture formed in the stomach is called chyme.

Exposure to some substances can cause nausea and vomiting, an unpleasant

![Figure 2.3 Organs of the digestive system](image-url)
experience where the stomach empties through the mouth. An example of this is exposure to parathion (a pesticide), which can enter the body through inhalation, absorption or ingestion. Symptoms of exposure to parathion include:

- irritation to the eyes, skin and respiratory system
- nausea
- vomiting
- abdominal cramps
- diarrhoea.

Excessive or continued exposure may lead to convulsions, lowered blood pressure and even cardiac irregularities.

The small intestine is where virtually all absorption of nutrients and substances occurs. The lining of the small intestine contains many folds to force the chyme to mix with intestinal juice and then the chemical contents are absorbed through finger-like projections called villi.

The cells within the small intestine divide very quickly and are renewed every three to six days. This is one reason why exposure to an acute dose of ionising radiation can damage the cells of the small intestine, causing nausea and vomiting followed by minor symptoms of malaise, diarrhoea and thirst.

The large intestine’s major role is to allow absorption of water and eliminate indigestible food residues through the anus as faeces. Exposure to some microbiological hazards found at work, such as *Escherichia coli* from poor sanitation practices, can produce toxins that cause gastrointestinal disturbances.

The large intestine may also play a role in hot and humid conditions such as working in an underground mine or in a laundry. As the sweat rate increases to lower the net heat retained by the body, less water is available for reabsorption through the large intestine.

### Accessory organs

The accessory organs to the digestive system include the liver, gall bladder and pancreas.

#### Liver

The liver is one of the body’s most important organs as it maintains blood glucose levels, metabolises fat and proteins, stores vitamins and minerals and has biotransformation functions. It converts hazardous substances into inactive products that can be secreted by the kidneys. However, sometimes the liver is unable to convert toxic substances to their less hazardous form.

Exposure to vinyl chloride monomer (a colourless gas used in the synthesis of PVC) can cause enlargement of the liver and fibrosis. In rare cases, continued exposure can cause liver cancer.

Selenium, a metallic alloy, is metabolised in the liver to dimethylselenide under conditions of high exposure. This reaction leads to a ‘garlicky breath’, as it is released through the lungs.

Hepatitis, or inflammation of the liver, is another virus that can be contracted from work, especially those working in high-risk areas such as hospitals, day care centres or nursing homes. More details about the various types of hepatitis are given in Chapter 10.

### ENDOCRINE SYSTEM

The endocrine system is often the unsung hero at work within the human body. The major endocrine organs are the:

- pituitary gland
- thyroid gland
- parathyroid gland
- thymus gland
- adrenal gland
- pancreas
- gonads.
The endocrine system manufactures and releases hormones. Hormones are chemical substances that provide directions and messages to the body’s cells. Generally speaking, they can be classified as either: amino acid-based hormones (most hormones) or steroids.

Hormones act on specific tissues or target cells. When the hormone is released it can travel throughout the body until it comes across a target cell that will respond. These target cells have specific protein receptors that couple with the hormone. The degree to which the hormone will combine with the target cell will depend on the:

- hormone’s concentration in the blood
- relative number of receptors available to couple with the hormone
- strength of attraction (affinity) between the hormone and the receptor.

IMMUNE SYSTEM

The body is constantly bombarded with hazards and ‘foreign invaders’. The body has three lines of defence against the invaders.

The front line

Skin and mucosa are the first, or front, line of defence. These are physical barriers between agents and the internal environment of the body and have the following characteristics:

- acidic skin secretions and surface
- acidic stomach mucosa
- saliva and lacrimal fluid containing lysoyzymes (an enzyme that destroys bacteria)
- mucous which traps many microorganisms in the respiratory and digestive systems.

The second line

The second line of defence is activated when the agent enters the body. Antimicrobial proteins ingest and destroy foreign agents and other cells to limit the invader’s spread. The process of engulfing these agents is called phagocytosis. The main phagocytes are macrophages. Free macrophages circulate throughout the body and are constantly looking for invaders to engulf. Other types of macrophage are fixed in a particular organ: for instance, Kupffer cells are found in the liver and alveolar macrophages are found in the lung. Another type of phagocyte are the neutrophils. These are a type of white blood cell that become phagocytic if they encounter a foreign substance.

In the blood and lymph, natural killer (NK) cells roam with the specific task of killing cancer cells and virus-affected body cells before the immune system is activated. As the name suggests, they are non-specific in their targets and act by attacking the cell’s outer layer, the plasma membrane.

The last line

The third, or last, line is a specific defence system or the immune system. The process is called immunity. Immunity involves a specific reaction between the invader (the antigen) and the protector (the antibody). It is particularly useful to the body as the immune response is transferred throughout the whole body and can quickly respond to a subsequent exposure with a ‘counter-attack’. The main types of immunity responses are: humoral (antibody-mediated) and cellular (cell-mediated).

Humoral immunity

A humoral immune response occurs when an antigen enters the body, causing the production of antibodies to fight the agent.
Antibodies, also called immunoglobins (ig’s), are classified according to their structures and type of antigen to which they will bind. The confrontation usually occurs in the spleen or lymph node, and involves a B-cell. B-cells are a type of lymphocyte (white blood cell) which are able to recognise and link to a specific antigen. As the antigen binds to the surface of the B-lymphocyte, it becomes activated, causing the cell to quickly multiply and form B-cells. By themselves, B-cells do not secrete large amounts of antibodies. However, B-cells formed from the original B-lymphocyte (called clones) change to plasma cells, which secrete antibodies to kill the antigens. Those few clone cells that do not become plasma cells, called memory cells, continue to circulate in the body and can quickly react to another invasion of the antigen if required.

Humoral immunity can be obtained in two ways. Firstly, it can be naturally acquired through viral or bacterial infections. Secondly, it can be artificially acquired by being exposed to a vaccine. For instance, exposure to vaccine against Q fever (the bacteria *Coxiella burnetii* is the causal agent) will cause the body to develop its own antigens and, if exposed to the fever, the body can fight off the antigens.

Hypersensitivity is a term used to describe a person’s reaction to an agent that is not considered normal. It is also called an allergy. A hypersensitivity response occurs when antibodies and antigens bind together to form complexes, and these are deposited in organs and cause inflammatory damage. This type of effect can be generalised as extrinsic allergic alveolitis.

Exposure to some micro-organisms can elicit a hypersensitivity response. For instance, mushroom farm workers exposed to mushroom compost containing *Micropolyspora faeni* and *Thermoactinomyces vulgaris* can suffer from a Type III mediated hypersensitivity reaction known as mushroom pickers’ lung.

**Cellular immunity**

Cellular or cell-mediated immunity occurs when lymphocytes defend the body. So, instead of antibodies fighting off the antigens, some types of white blood cells have this responsibility. T-cells are best suited for this attack as they respond to processed fractions of protein antigens that are displayed on surfaces of the body’s own cells. A full description of cellular immunity is complex and beyond the scope of this discussion. However, you should be aware that there are a number of T-cells that play a role in the immune response. This type of response is also

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**Case study 2.1**

Jules is a jewellery maker. She notices a red rash on her hands, which persists after several months. Jules consults an occupational physician, who diagnoses the rash as allergic contact dermatitis, caused from exposure to nickel.

The doctor tells Jules that this is an example of a cell-mediated hypersensitivity or Type IV sensitivity. It is caused by an immune response between the proteins of the skin and the nickel molecules, which then produces T-cells. Jules informs the doctor that this was not the first time she had used alloys containing nickel. This is not unusual, as T memory cells may be formed after the first contact with no resulting dermatitis; however, subsequent exposures will result in dermatitis as the T memory cells form many active T-cells to fight the invader.

The doctor tells Jules that this is an example of a cell-mediated hypersensitivity or Type IV sensitivity. It is caused by an immune response between the proteins of the skin and the nickel molecules, which then produces T-cells. Jules informs the doctor that this was not the first time she had used alloys containing nickel. This is not unusual, as T memory cells may be formed after the first contact with no resulting dermatitis; however, subsequent exposures will result in dermatitis as the T memory cells form many active T-cells to fight the invader.
found chiefly when the B-cell has not been able to remove the agent and it has multiplied within the body quite quickly. Some examples of this include exposure to viruses, bacteria and cancerous cells.

**INTEGUMENTARY SYSTEM**

The skin and its derivatives (hair, nails, sweat and oil glands) are among the best mechanisms that the human body has to protect itself against occupational hygiene hazards. This system provides protection against physical hazards such as heat, radiation and abrasion, chemical substances and bacteria. Additionally, this system has many receptors that respond to external stimuli, it synthesises vitamin D and it is involved in a limited amount of excretion of nitrogen-containing wastes such as urea and ammonia. The skin is composed of two layers: the epidermis and the dermis.

The outer layer (the epidermis) is a thick covering that has four cell types and four or five separate layers. The cell types include:

- **keratinocytes**
- **melanocytes**
- **Merkel cells**
- **Langerhans’ cells**

The fibrous protein in the epidermis (keratin) forms one of the protective characteristics of the skin. As the name suggests, keratinocytes

![Figure 2.4 Structure of the skin](image-url)
manufacture keratin. Melanocytes are found deep in the epidermis and synthesise melanin, the pigment that helps protect skin cells from UV radiation. Exposure to substances such as p-tert-butylphenol (PTBP), which is an ingredient in resins used in adhesives in the motor industry, can cause vitiligo, a depigmentation of the skin.

Merkel cells are also located deep in the epidermis and combine with a sensory nerve ending. Langerhans’ cells are essentially scavenger cells which have migrated from the bone marrow to assist in the immune effect of the body.

The epidermis also has several layers, although the number will depend on the thickness of skin. These layers are the:

- **basal layer (stratum basale)**
- **spiny layer (stratum spinosum)**
- **granular layer (stratum granulosum)**
- **clear layer (stratum lucidum)**
- **horny layer (stratum corneum).**

Thick skin, found on the palms, fingertips and soles of the feet, has five layers. In thin skin, only four layers are present (the clear layer is missing).

The dermal region contains a large number of blood vessels and nerve endings. This is for several reasons. Firstly, the skin regulates body temperature by increasing or limiting perspiration. When the body temperature rises, the blood vessels in this area dilate and sweat is lost through sweat glands and to the pores of the skin. If the body becomes too cool, the blood vessels constrict to conserve body temperature. Secondly, the sensory receptors respond to stimuli such as temperature, pain and irritation. Finally, the extremely vascular nature of skin makes it an ideal blood reservoir. When blood is needed in other organs, the volume of blood sent to the dermal blood vessels is decreased.

Derivatives of skin, including hair follicles, oil glands and sweat glands, are located in the dermis. Hair is produced by hair follicles. Hair follicles extend from the epidermal surface of the skin deep into the dermis. At the base of the follicle is a bundle of smooth muscle, the arrector pili, which controls the movement of the hair. In the workplace, hair filters out large particles such as dusts from the respiratory system. It also protects the eyes from foreign particles.

Oil (sebaceous) glands are found everywhere on the body except the palms and soles. They secrete sebum, an oily liquid that is usually secreted at the hair follicle to coat the hair, making it water-resistant and killing bacteria. Acne occurs when an oil gland becomes inflamed and pimples show on the skin (this is caused by a bacterial infection or exposure to some chemical substances). Oils, pitch, tar and some chlorinated hydrocarbons can cause occupational acne. These chemicals clog the pores and then promote the production of keratin, forming cysts.

Sweat glands are distributed over the skin except the nipples and part of the external genitalia. The eccrine sweat glands are coiled, tubular glands that open at pores, excreting sweat. Apocrine sweat glands secrete sweat, proteins and some fatty substances. The secretion is odourless but can have a musky odour if decomposed by bacteria on the skin.

Exposure to some substances can cause sensitisation of the skin. This occurs when the sensitising substance travels through the epidermis and reacts with proteins in the dermis to form an antibody. This is known as contact dermatitis and the skin will react whenever the body is reacquainted with the substance. Some examples of sensitisers are:

- **dyes, such as aniline black, safranine and bismarck brown**
- **photographic developers containing hydroquinone or bichromates**
- **insecticides, such as creosote, tar and pyrethrum**
- **natural resins from timber.**
LYMPHATIC SYSTEM

The lymphatic system consists of lymphatic vessels and lymphatic tissues and organs. Their combined purpose is to assist the body in maintaining fluid equilibrium and protect against foreign invaders and diseases. The lymphoid organs include the lymph nodes, tonsils, thymus, spleen and Peyer’s patches (in the intestine).

These organs are formed from lymphatic tissue. Lymphatic tissues house scavenger cells, known as lymphocytes and macrophages. Lymphocytes originate from the red bone marrow (from long bones such as the femur and clavicle) and then mature into T-cells or B-cells. T-cells directly attack and destroy foreign cells, while B-cells form plasma cells that secrete antibodies to immobilise the foreign cell until it can be destroyed by other means. These foreign cells are called antigens. In the human body, an antibody will be developed for
a specific antigen. Macrophages are involved in destroying foreign bodies in the body. This process is called phagocytosis.

Lymphatic vessels collect fluid that is in tissue spaces (interstitial fluid), where it is drained and returned to the bloodstream. Once the fluid enters the lymphatic vessels it is called lymph. Since there is no central 'pumping station' for the lymphatic system (as opposed to the cardiovascular system), the vessels have a specialised structure that allows lymph to be collected from the interstitial space and transported throughout the body. Lymph is collected initially by lymphatic capillaries. These then expand to successively larger and thicker-walled vessels until finally being delivered to one of two large ducts in the thoracic region.

**MUSCULAR SYSTEM**

Muscle tissue can be skeletal, cardiac and smooth. Each type has different functions within the body and all can be affected by exposure to occupational hygiene hazards. Skeletal muscle can be damaged if over used. In general, the function of muscle is to:
• produce movement
• maintain posture
• stabilise joints
• generate heat.

Muscle tissue is able to receive and respond to a stimulus, can contract and extend, and has an ability to return to its original length after being stretched. Skeletal muscles are actually thousands of smaller muscle work-units called muscle fibres. Muscle fibres are covered in a protective layer of connective tissue known as the endomysium. The muscle fibres in turn are formed from many contracting elements called myofibrils. Myofibrils are complex structures that consist of myofilaments (also known as sarcomeres), laid end to end, which contract and expand.

Myofilaments contain thick and thin contractile proteins that contain myosin (thick) and actin (thin), respectively. These proteins slide past one another, enabling the muscles to shorten. This is the reason why skeletal muscle is often referred to as being banded or striated — the thick and thin filaments within the myofibril give the muscle fibre a striped appearance.

Muscle fibres are then bundled together and called a fascicle (or portion of the muscle). This is surrounded by a perimysium. Hundreds or thousands of muscle cells, connective tissue, blood vessels and nerve fibres are then bound to form a muscle. Muscles are also covered with an external layer called the epimysium.

Skeletal muscles are arranged in the body so that they either work together or in opposition, to achieve a variety of movements.

Figure 2.7 The relationship between agonist and antagonist muscles
Since muscles contract and hence only pull, another muscle must pull in the opposite direction to ‘undo’ the action. The muscle that provides a specific force for a movement is called the agonist. Its opposite partner is called the antagonist. The antagonist is often stretched and relaxed while the agonist is active. Another type of muscle that assists in action is called the synergist. This muscle aids in the movement and prevents unwanted movements or action that might occur when the agonist contracts.

Smooth muscle is found in the walls of hollow organs of the respiratory, digestive, urinary and reproductive tracts. They are also part of the multi-unit muscles of the intrinsic eye muscles. Their contraction occurs involuntarily as compared to skeletal muscles whose contractions are voluntary. Cardiac muscle, as the name suggests, refers to the muscle of the heart. It also operates involuntarily but rhythmically.

**NERVOUS SYSTEM**

The nervous system is our body’s ‘computer’. The central nervous system (CNS) consists of the brain and spinal cord, and functions as the body’s control centre. The peripheral nervous system (PNS) is the workhorse — it consists of spinal nerves that carry impulses to and from the spinal cord and cranial nerves that carry impulses to and from the brain.

Nerves are made from nervous tissue. Nervous tissue consists of neurons and
supporting cells. Neurons consist of the cell body, processes, dendrites and axon. Most cell bodies are found in the CNS. Extensions called processes move out of the cell body. Processes can be dendrites or axon.

Dendrites are short processes that conduct electrical impulses toward the cell body. The axon is joined to the cell body at the axon hillock. The other end of the axon that connects with other neurons or a tissue, such as muscle, is called the axon terminal. It transmits electrical impulses away from the cell body.

The axon can be covered in a fatty sheath, called the myelin sheath. The sheath helps insulate the axon, increasing the speed of impulse transmission and electrically isolating one axon from another. The sheath is formed from a number of Schwann cells that are wrapped around the axon. Schwann cells are an example of supporting cells and are only found in the PNS. There are usually gaps in between the sheath and these are called nodes of Ranvier.

The nervous system is one of the major systems that can be affected by acute exposure to occupational hygiene hazards. For instance, exposure to n-butane (a flammable gas) can cause drowsiness and is narcotic. Bromoform is a CNS depressant.

Neurons respond strongly to stimuli. When they are adequately irritated, an electrical impulse is conducted along the axon. This is known as a nerve impulse or action potential. When a nerve impulse reaches the axon terminal, a chain of events causes a substance
to be released that assists in the transmission of the electrical message. This substance is known as a neurotransmitter. The neurotransmitter crosses the junction between neurons, or a neuron and effector cell (the synaptic junction), and causes a change in the permeability of the postsynaptic membrane. From here, depolarisation of the membrane causes calcium ($\text{Ca}^{2+}$) to flood into the terminal. This surge then causes the neurotransmitter contents to be emptied into the synaptic cleft, where it attaches to receptors in the postsynaptic membrane. As the neurotransmitter binds to the postsynaptic membrane, a voltage change occurs causing it to be excited or inhibited.

There are many types of transmitters found in the human body. The first neurotransmitter to be identified was acetylcholine (ACh). After acetylcholine is released, it binds to the postsynaptic receptors and is then degraded by the enzyme acetyl-cholinesterase (AChE). Acetylcholine is released by all neurons that stimulate skeletal muscles. Cholinesterase (measured in blood) can be used to determine if workers have been exposed to organophosphorous pesticides.

**REPRODUCTIVE SYSTEM**

The male reproductive organs include the:

- **sperm producing area — the testes that are located inside the scrotum**
- **duct system — consisting of the**
epididymis, the vas deferens and urethra.

The process is also aided by the seminal vesicle, which secretes fluid into the ejaculatory duct, and the prostate gland.

The occupational hygiene hazards that can affect the male reproductive system are chemical, physical and biological in nature. Some substances such as lead and pesticides can lead to the production of abnormal sperm. Physical hazards such as radiation and heat may interfere with sperm development. Sterility from exposure to viral infections such as mumps is a rare but possible consequence.

The female reproductive system consists of the internal organs:

- ovaries
- fallopian tubes
- uterus
- cervix
- vagina.

It also includes the external genitalia. The mammary glands are considered to be an accessory organ of the female reproductive system. The reproductive system hazards that affect females are similar to males; however, exposure to teratogens must also be considered if the woman is pregnant and at work.
Figure 2.12   Electrical impulse transmission

Figure 2.13   The male reproductive system
The respiratory system consists of two areas — the conducting zone and the respiratory zone. The conducting zone consists of the nasal and oral cavity, which funnels air from the external environment through the trachea and into the branched structures of the lungs (bronchi). The trachea and bronchi are constructed of a connective tissue called cartilage that helps maintain their structure to prevent collapse and allow air to travel into the smaller bronchioles. Air then travels along the bronchioles and to its ending (the terminal bronchiole) which is covered in tiny sacs. These are called alveoli. Alveoli have the role of increasing the surface area available for gas exchange in the lung. They resemble a bunch of grapes on the end of a stalk. As air is conducted through the bronchioles it is forced into the alveoli that expand from the pressure of air. Since the alveolar wall is only about one cell thick, the air diffuses across the membrane and into the capillaries. This area is known as the respiratory zone.

Exposure to substances at work through inhalation will show different effects depending on their movement through the conducting zone and the respiratory zone. Water-soluble gases such as ammonia (NH₃) and chlorine (Cl₂) will dissolve in the upper respiratory tract. These gases may irritate the eyes and nasal mucosa and cause itching or stinging of the nose and throat and watering eyes. Other more permanent gases, such as carbon monoxide (CO), will travel through the conducting zone and pass across the alveolar wall to the oxygen-carrying cells of the blood, the red blood cells (RBC) or erythrocytes. These cells contain a protein, globin, and a red pigment, haem. Every haemoglobin molecule contains four ring-like haem groups with an iron atom in its centre. It is the iron atom that

Figure 2.14 The female reproductive system

RESPIRATORY SYSTEM

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combines with oxygen to collect, transport and unload this gas from the lungs to the tissues of the body. Therefore, four oxygen molecules are transported in each haemoglobin molecule.

Some fibrotic dusts such as crystalline silica, which was formerly used as an abrasive blasting media, do not pass through the alveolar wall but are instead removed from the lungs by scavenging cells from the immune system. Macrophages, a type of white blood cell that recognises foreign particles (antigens), play an important role in engulfing and destroying these particles.

Once the oxygen has diffused through the alveolar wall and bound with the haemoglobin, it is then transported throughout the body tissues. Carbon dioxide (CO₂), a by-product of normally active body cells, is then collected from the tissues to be excreted by the lungs.

Carbon dioxide can be transported in the following forms:

- **as a gas dissolved in the plasma of blood** — about 7–8 per cent of carbon dioxide transported simply dissolves into the plasma
- **chemically bound to haemoglobin in red blood cells** — about 20 per cent of carbon dioxide is transported this way; as the red blood cells reach the lungs the carbon dioxide is rapidly dissociated and transfers across the alveolar wall into the lung
- **as bicarbonate ion in plasma** — about 70 per cent of carbon dioxide is converted into bicarbonate ions and transported in the blood plasma.
Once the carbon dioxide reaches the respiratory zone and passes through the capillaries covering the alveoli, it either dissolves or dissociates, moves into the alveoli and is exhaled for elimination from the body.

**SKELETAL SYSTEM**

The skeletal system consists of two main parts: the axial and the appendicular skeletons (Figure 2.16).

The skeleton’s main function is to support, protect and allow for movement by the long bones that act as levers. From an occupational health perspective the skeleton also has another important function: storage of fat and minerals. Calcium and phosphorous are the most important minerals stored in the matrix of the bone, although copper, magnesium, potassium, sodium and sulphur are also stored. Some metals such as lead, which is used in manufacturing car batteries, some pipes, paints, enamels, glazes, leaded petrol and in radiator repair, will actually displace calcium from the bone and teeth. Once inside the body, the metal compound is quite stable.

The skeleton also manufactures blood cells

---

**Figure 2.16** The human skeleton

![The human skeleton diagram](image-url)
within the marrow cavities of long and flat bones. Exposure to inorganic lead, benzene or carbon monoxide can cause stippling of the red blood cells. This is a condition, known as sickle-cell anaemia, where the red blood cells become crescent shaped and rupture prematurely which results in the blood having a reduced oxygen-carrying capability.

The axial skeleton is made of the skull, vertebral column and bony thorax. Its main purpose is to protect nervous tissue, such as the brain and spinal cord, and organs behind the ribs and sternum.

The bones of the appendicular skeleton can be thought of as two bony girdles attached to the axial skeleton, with more bones attached to each girdle. Attached to the bony thorax by the clavicle and scapula, the pectoral or shoulder girdle attaches to the arm, forearm and hand. The pelvic or hip girdle is secured to the axial skeleton by strong ligaments. It consists of a bowl-like structure (the pelvis) which articulates with the thigh bones through ball-and-joint sockets. Beginning at the thigh, the bones of the leg are the femur, tibia and fibula. The kneecap (patella) forms a hinge between the upper and lower leg, and the foot and toe bones support the weight of the body.

**URINARY SYSTEM**

The kidney is the major organ that is involved in excretion and maintaining a constant internal environment. The skin and lungs are also involved in excretion.

Kidneys can be best described as bean-shaped organs that lie either side of the vertebral column. They have a rich blood supply, enabling them to cleanse the blood of toxins and remove or retain water in blood to ensure a stable volume of blood. This cleansing occurs through the nephrons. Most people have two kidneys, with each containing more than one million nephrons. As blood from the renal arteries delivers blood to the kidneys, it filters through an area called the glomerulus that is very dense in capillaries. As blood passes through these capillaries, large amounts of liquid seep out of the glomerulus and into its surrounding area, the glomerular (Bowman's) capsule. These two parts of the nephron are known as the renal corpuscle. From here, the liquid makes a journey through the proximal convoluted tubule, takes a sharp U-turn at the loop of Henle and then continues in the distal convoluted tubule. This part of the

---

**Figure 2.17 Cross-sectional diagram of the kidney**
kidney is found at the cortex-medulla junction and is the area most significantly damaged by exposure to occupational hygiene hazards.

As the liquid, or filtrate, travels through the tubules, capillaries that surround the tubules reabsorb a large amount of the liquid. The proximal convoluted tubule reabsorbs:

- **sodium ions** ($\text{Na}^+$)
- **nutrients such as glucose, vitamins and amino acids**
- **ions such as potassium** ($\text{K}^+$), **magnesium** ($\text{Mg}^{2+}$), **calcium** ($\text{Ca}^{2+}$), **chloride** ($\text{Cl}^-$) and **hydrogen carbonate ions** ($\text{HCO}_3^-$)

Water, small proteins, urea and fat-soluble solutes can also be reabsorbed. Chloride sodium ions and water continue to be reabsorbed at the loop of Henle. The distal convoluted tubule reabsorbs sodium, water and anions (negatively charged ions). This is known as tubular secretion. Tubular secretion assists in disposing of substances that are not already in the filtrate, can help control the pH (acidity) of the blood and eliminates undesirable substances that have been reabsorbed.

After moving through the loop of Henle, urine concentrates and is conveyed from the kidneys to the bladder via the ureters. Urine
consists of about 95 per cent water and only 5 per cent of solute. The urinary bladder is a muscular sac that temporarily stores urine until draining from the body by the urethra.

Some substances can be measured in urine, as they are not fully metabolised by the body and are not reabsorbed through the excretory system. The term used for this type of measurement is biological monitoring. Table 2.1 shows some examples where urine samples can be collected to detect substances (or indicators of their presence).

**ANATOMICAL POSITIONS**

Let's face it, studying the human body at work can be complex. Work requires many movements and placement of body parts at different angles and locations.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Substance or metabolite monitored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>t,t-muconic acid (t,t–MA)</td>
</tr>
<tr>
<td>Carbon disulphide</td>
<td>2–thiothiazolidine–4–carboxylix acid (TTCA)</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>trichloroacetic acid (TCA)</td>
</tr>
<tr>
<td>Xylene</td>
<td>methyl hippuric acid</td>
</tr>
</tbody>
</table>

**Table 2.1 Biological Monitoring (Urine) for Selected Substances**

![Anatomical terms for the human body at work](image)

Figure 2.19 Anatomical terms for the human body at work
Anatomists use certain medical terms to describe the direction and position of organs within the body. They describe the body in terms of sections or planes. For instance, the frontal plane divides the body into front (anterior) and back (posterior) parts. The sagittal plane cuts the body into left and right sections. The transverse plane runs horizontally through the centre of the body to divide it into top (inferior) and bottom (superior) parts. These examples are shown in Figure 2.19. Movements of the body are also described in Figure 2.20.
SUMMARY

The human body at work is an amazing piece of machinery whose systems work together to adapt to continual change and variation. Exposure to occupational hygiene hazards constantly challenges the body to maintain homeostasis. The twelve systems in the body that work to achieve this internal consistency are the cardiovascular, digestive, endocrine, immune, integumentary, lymphatic, muscular, nervous, reproductive, respiratory, skeletal and urinary systems.

BIBLIOGRAPHY AND FURTHER READING

Marieb, E.N. 1997, Essentials of Human Anatomy and Physiology, 5th edn, Benjamin/Cummings Inc., California
Earlier in this book, the broad principles of risk management were identified as hazard identification, risk assessment and risk control. In Australian workplaces, occupational health and safety laws require a structured approach to hazard identification. However, this need not mean the task is onerous. Recognition of hazards, especially those that impact on the health of workers, can be performed in a number of ways: both formally through the engagement of specialists and informally by involving trained workers in the process. AS/NZS4801 and AS/NZS4360 provide broad guidance in the area by suggesting that all hazards should be identified as part of an ongoing process and especially where there are changes in the workplace, new knowledge about the hazard or changes in legislation.

This chapter provides some practical hazard identification tools and techniques including inspections; occupational hygiene audits; consultation and communication; using information or specialist advice; reviewing records; and job safety analyses.

INSPECTIONS

One of the most common methods of identifying hazards is the inspection or walk-through survey. Inspections can focus on a specific physical area of the workplace or may be hazard specific. Equally, they can be performed in a structured or planned way, or may be part of day-to-day work and are thus unplanned or casual. Whatever the level of formality in conducting an inspection, what is integral is that hazards are identified and controlled to minimise risk.

In recent years, the application of occupational health and safety inspections has broadened to encompass the identification of unsafe/unhealthy acts, as well as unsafe/unhealthy conditions. The latter refers to the physical hazards. The former considers the role of workers and management and the impact of their behaviour on health and safety outcomes. This section of the chapter will focus on physical conditions while the discussion on consultation and communication will delve into the aspect of human involvement.

Physical inspections generally involve walking around various areas of the workplace to identify hazards that may be observed or anticipated. While investigating the physical environment and conditions, it is vital that further information is obtained from workers or their representatives to gauge the full picture. Workers have an intimate knowledge about what is actually done at the workplace and whether the conditions are representative of a typical day’s exposure. For instance, has an exhaust fan been switched off for maintenance, resulting in high dust concentrations in the workshop? Why are
solvent-drenched rags lying in opened drums near paper and timber offcuts? Workers may be able to explain these anomalies, describe changes that have been made and report how the conditions may be affecting them. The advantages of an inspection as a technique for hazard identification are:

- **it can be quick**
- **the workplace can be investigated as separate processes or areas**
- **a multidisciplinary team of workers, occupational hygienist and management can give a holistic and unbiased assessment**
- **baseline information about the current status of health can be determined and benchmarked**
- **tools such as checklists can be used to guide and assist the investigating team.**

Checklists are one of the most commonly used tools to identify occupational hygiene hazards. Many types of checklists can be found in occupational hygiene texts and also on the Internet. However, they may need to be adapted to suit the workplace and hazards.

At best, checklists should be used as guidance and to jog the memory. Some occupational hygienists find it useful to skim the checklist once the inspection or audit has been completed. This serves as a backup to the process that had been conducted. The advantages of checklists are that they provide suggested areas or hazards to investigate, guide the investigator to hazards which may not have been thought of, provide a format for reporting and recording findings, and give structure and direction to the investigation.

Limitations of using checklists as the sole hazard identification tool are they can ‘blinker’ the investigator, who refers only to the checklist, and some formats of checklists do not provide adequate space for recording details of conditions.

Inspections are an important systematic tool that may be used to identify areas of noncompliance or potential risk to workers. They can be designed using a problem-solving approach and then be expanded upon to generate discussion and manage risks in the workplace. Unfortunately, inspections are limited in that:

- **they take a ‘snap-shot’ of the conditions at a particular point of time**
- **the investigators’ knowledge may limit the hazards that are identified**
- **systems and procedures are not fully investigated**
- **insidious and non-obvious hazards may not be recognised.**

At first, conducting an inspection may appear daunting! Significant planning may be required to become familiar with the type of workplace and its potential hazards. A good understanding of the inputs, outputs and by-products or intermediates of the process is also required. Hazards may be present at any of these stages. The five steps of conducting an inspection are planning, investigation, evaluation, reporting and taking actions.

**Planning the inspection**

This will require considering aspects or areas to be inspected and determining the measurable standards with which to compare the findings. As a starting point, the relevant State, Territory or Commonwealth occupational health and safety legislation should be consulted to identify the minimum standard of control that must be achieved.

The minimum standards need not be merely legislative requirements but could include industry standards or accepted ‘best practice’ standards. Most legislation is available on the Internet or may be purchased through the State, Territory or Commonwealth...
government publishing services. The websites for the State, Territory and Commonwealth departments responsible for occupational health and safety are shown in Table 3.1.

**Table 3.1 OH&S websites in Australia**

<table>
<thead>
<tr>
<th>Government authority</th>
<th>Internet address (URL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland</td>
<td><a href="http://www.whs.qld.gov.au">www.whs.qld.gov.au</a></td>
</tr>
<tr>
<td>New South Wales</td>
<td><a href="http://www.workcover.nsw.gov.au">www.workcover.nsw.gov.au</a></td>
</tr>
<tr>
<td>Victoria</td>
<td><a href="http://www.workcover.vic.gov.au">www.workcover.vic.gov.au</a></td>
</tr>
<tr>
<td>Tasmania</td>
<td><a href="http://www.workcover.tas.gov.au">www.workcover.tas.gov.au</a></td>
</tr>
<tr>
<td>South Australia</td>
<td><a href="http://www.workcover.sa.gov.au">www.workcover.sa.gov.au</a></td>
</tr>
<tr>
<td>Western Australia</td>
<td><a href="http://www.safetyline.wa.gov.au">www.safetyline.wa.gov.au</a></td>
</tr>
<tr>
<td>Northern Territory</td>
<td><a href="http://www.deet.nt.gov.au/wha">www.deet.nt.gov.au/wha</a></td>
</tr>
<tr>
<td>ACT</td>
<td><a href="http://www.workcover.act.gov.au">www.workcover.act.gov.au</a></td>
</tr>
<tr>
<td>Commonwealth</td>
<td><a href="http://www.w.comcare.gov.au">www.w.comcare.gov.au</a></td>
</tr>
</tbody>
</table>

The planning phase will also involve selecting a team to participate in the inspection. The team should be balanced with workers or their representatives, supervisors or management, and a person with skills, knowledge and experience in identifying occupational hygiene hazards.

This may require some negotiation to obtain the best balance of team members in a setting that is still informal and easily managed. It is important to remember that the inspection is not a fully fledged audit but a preliminary survey of the conditions.

**Investigation**

The investigative component of the walk-through survey will require the team to make basic observations about the work environment, workers and the work process. Some aspects that should be investigated will include:

- **the process** (inputs, outputs and by-products)
- **the nature and state of matter of substances or agents involved in the process**
- **temperature and pressure of the process**
- **the number of workers involved in the process and those who may be exposed**
- **immediately observable conditions** such as excessive noise, dusts, fume, lighting
- **controls currently in place and whether they are being used**
- **the use of personal protective equipment** such as respiratory protective devices, hearing protection, gloves and eye protection
- **visible health effects that may be associated with exposure to substances from the process.**

**Evaluation**

The evaluative phase allows the identified hazards to be compared with measurable standards and decisions to be made as to the requirement for further information to assist in the risk assessment. Conducting occupational hygiene monitoring may require quantification of the risks. For instance:

- **monitoring of noise levels and frequencies at a canning factory**
- **measurement of lighting levels and glare in an office environment**
- **measurement of temperature in a bakery.**
It may be difficult to make a full evaluation of conditions following an inspection. Other techniques for hazard analysis are detailed in Chapter 13.

**Reporting and taking action**

The findings of the inspection should be documented in a report or findings sheet. Due to the informal nature of the survey, it may not be practical to complete a full technical report but an action sheet with responsibilities is a necessity.

Other options for reporting the findings of the walk-through survey will depend on the nature of the inspection. For instance, if the purpose was to identify the presence of hazardous substances, a plan of the workplace could be drawn to show its physical layout and the location of substances. The recommended controls should be implemented and reviewed for their effectiveness within a particular time frame. This will help to manage the risks and ensure continued participation from all levels of the workforce. Chapter 14 discusses ways of managing risks.

**OCCUPATIONAL HYGIENE AUDITING**

Occupational hygiene auditing expands the inspection to identify hazards and measure the effectiveness of the occupational hygiene program against goals and standards. The audit enables obvious occupational hygiene hazards to be identified and the systems for recognition of hazards to be evaluated. There are four components of an occupational hygiene audit:

- **to review the program’s organisation and procedures**
- **to evaluate trends in illness**
- **to review methods for recognition, evaluation and control of hazards**
- **evaluate training and communications.**

A comprehensive audit may take several hours or even days, depending upon the workplace and its systems. However, whether an organisation has complex or simple systems, the principles of auditing are identical. The relationship between workers, management, plant and equipment, procedures, materials and the environment must be considered.

Various occupational health and safety audit frameworks are used in Australia. The most common of these are AS/NZS4801, OHSAS18001 and SafetyMAP. Further information about auditing is presented in Chapter 14.

**Policies and procedures**

Policies and procedures relating to the occupational hygiene program should be reviewed to ensure they:

- **enable an adequate and efficient use of resources**
- **meet the goal of identifying hazards and minimising risk**
- **achieve the stated goals** (for instance, that exposure to a hazardous substance is less than the NES)
- **are able to adapt to changes in the program focus.**

The program should be checked for content and applicability at the workplace. For instance, have relevant minimum legislative requirements been identified and how was this done? Has responsibility been delegated to ensure the organisation is aware of recent information about the substances or agents used in the workplace?

Emergency procedures and communication between workers and management should also be investigated. The methods and
effectiveness of reporting/recording of accidents and illness should be reviewed through discussion with workers, comparing hazard identification or accident reporting forms, and workers’ compensation data.

Any documentation relating to managing occupational hygiene risks should be maintained, reviewed and supported by management at the highest level. Commitment by all levels of the workforce is vital to gain a sense of ownership and empowerment of the system. Disenchanted workers may not be willing to identify occupational hygiene hazards if they believe their opinions will not be taken seriously and appropriately actioned.

**Evaluating trends**

Evaluating trends in injuries and accidents is one indicator that can be used to determine the effectiveness of the occupational hygiene program. Earlier in Chapter 1, terms such as prevalence and incidence were discussed. If these are tracked over a period of time, particular patterns may become apparent.

The disadvantage of adopting this type of approach is that such evaluations are negative indicators, as compared to a proactive or positive analysis of performance. The advantages, however, lie in the ability to identify unsafe conditions and unsafe workplace practices. Costs associated with occupational illness can also be analysed with potential savings highlighted.

**Reviewing risk management systems**

This part of the occupational hygiene audit allows review of hazard recognition procedures and documentation such as walk-through surveys, area plans of the workplace, material safety data sheets and job safety analyses.

The mechanism for worker consultation and feedback with management should also be reviewed at this stage. Other aspects that could be investigated include:

- the adequacy of process and equipment design to control or minimise exposure
- that standard operating procedures (SOP) are in place and are reviewed regularly
- procedures for personal protective equipment (PPE), which might include assignment of equipment to

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**Case study 3.1**

The manager of a large open-plan office that housed telemarketers had received recent complaints of general feelings of unwellness from personnel. The symptoms included dryness of the eyes, running nose and headache.

Upon investigation of the complaints, she noticed that most were from the afternoon shift, which began at 3 p.m. and finished at 10 p.m. At first, the manager assumed the comments had stemmed from a worker who stirred up other employees who then became vocal about minor issues. Only a week previously they had complained that the tearoom was stuffy.

The manager contacted the owner of the building, who informed her that the air-conditioning was on an automatic timer that switched off at 6 p.m.! The manager notified the building owner that employees were working until 10 p.m. The timer was adjusted to turn off at 10 p.m. and an ‘out-of-hours’ switch was also installed.
workers, maintenance, control and use
• management audits and their frequency, the personnel involved and the methods for follow-up
• worker training programs
• emergency response capabilities.

Training and communication

The aim of this section of the audit is to review the worker training programs for relevance; success in informing, motivating and modifying worker behaviour; and ability to convey management’s commitment to a healthy work environment. Some issues that may be investigated and checked are:

• procedures for induction
• hazard communication training
• ‘on-the-job’ training programs
• written communication
• frequency and content of employee meetings and awareness programs
• consultation mechanism and method of obtaining feedback such as ‘toolbox’ talks and round-table meetings
• professional training skills of the ‘trainers’. For instance, are they occupational hygienists, engineers, production management or employee relations staff?

When to audit?

The frequency of auditing will depend on its aims and application. For instance, is the audit’s chief goal to determine compliance with legislation or is it to identify hazards? Audits can be conducted periodically, intermittently, continuously or on special occasions.

Periodic audits are scheduled at regular intervals and may include auditing of specific hazards; for instance, buildings and grounds, general housekeeping, hazardous substances, portable hand tools and ergonomics.

Intermediate audits are made at irregular intervals and are usually unannounced, for example, emergency evacuation procedures and confined space entry procedures.

Continuous audits are part of the workplace’s day-to-day operation. Responsibility is usually allocated to all people in the workplace and continual improvement is the goal in this case.

Special audits are for especially hazardous situations, such as lighting, container labelling, hearing protector audits and use of gloves.

USING INFORMATION OR SPECIALIST ADVICE

Effective hazard identification requires considerable awareness of the potential agents that may be present in the work environment. There is much information that can be sourced to assist in identifying occupational hygiene hazards. These are available in different media such as books, journals and periodicals, legislation, brochures and information sheets, CD-ROM, the Internet, floppy disc, microfiche, video, computer databases and organisational literature.

Some books that may be useful are shown in the Bibliography and Further Reading section of this chapter. As a general rule of thumb, books should be used to provide general information but should not be heavily relied upon as the primary source of information. Writing, publishing and editing delays often mean the information contained in a book could be six or twelve months old before even getting to the bookstore! Although this is not always the case, remember to consider the publication date of the book and check details until you are comfortable the information is recent and relevant.

Journals and periodicals provide recent research findings and discussion about issues
relating to a particular topic. They are usually peer-reviewed and the authors must meet stringent publication requirements. Some useful occupational hygiene journals include:

- The Annals of Occupational Hygiene
- American Industrial Hygiene Association Journal
- Journal of Occupational Health and Safety — Australia and New Zealand
- Journal of Occupational Medicine
- Applied Occupational and Environmental Hygiene
- American Journal of Epidemiology

The contents of these journals can be found in some libraries on CD-ROM or online. Universities that specialise in occupational health and safety or occupational hygiene should be the first port of call.

Computer databases can contain factual information or bibliographic details about a particular topic. They can be accessed through CD-ROM or directly online, although the cost of accessing this information online is still expensive and charged by the minute.

Organisations such as libraries and government departments may also provide services to help identify occupational hygiene hazards. Public and university libraries contain many excellent starting points in this search. While public libraries are easily accessible, most university libraries will allow only enrolled students to access this type of information. The NOHSC offers a service (for a small fee) where key words can be searched in a number of databases. The findings are then provided as a bibliography or as the papers themselves.

Some companies will also have private libraries and information about occupational hygiene risks. State, Territory and Commonwealth government departments mostly have libraries, documents, brochures and information sheets to help identify hazards.

Lastly, occupational hygiene consultants should be able to provide current and significant information about occupational hygiene hazards. While it may be difficult to identify such a professional from the telephone directory, the Australian Institute of Occupational Hygienists is the professional organisation that has a list of members who may assist in matters such as these.

REVIEWING RECORDS — MATERIAL SAFETY DATA SHEETS

If chemical substances are used at the workplace, one of the best sources of information is the material safety data sheets (MSDS). The MSDS are documents that identify:

- the ingredients and their physical properties
- the product name
- the use and composition of the product
- health effects/hazards
- safe handling information
- precautions for use.

While the inspection or audit are tools that can be used to identify hazards, the MSDS provide specific information about the nature of a substance and possible health effects. They are developed by the manufacturer or importer of the substance and should be supplied with the substance.

The real aim in producing and providing MSDS is to ensure a flow of information about the hazardous nature of substances and ways to minimise the risk associated with exposure to the substance.

As a hazard identification technique, the MSDS can assist in:
• identifying the hazardous component of a substance or process
• using the substance correctly and with a minimum of risk
• providing recommendations for control and the rationale for these suggestions
• explaining the consequences of exposure, including symptoms of overexposure
• informing workers and the employer about the substances that are being used at the workplace.

The NOHSC has developed a national code of practice for the preparation of MSDS. This document describes essential (core) information that must be included in the MSDS and conditional information which should be included where relevant. It must be noted, however, that this document is only enforceable where the Australian States, Territories or Commonwealth includes it in their occupational health and safety legislation. As a ‘stand-alone’ document, it has an advisory function.

The core information that should always be in the MSDS include:

• statement of the hazardous nature of the substance according to the approved criteria for classifying hazardous substances
• company name, address, telephone number and emergency number
• date of issue of the MSDS
• page numbering
• product name and other names
• use of the product
• manufacturer’s product code, UN number, dangerous goods class and subsidiary risk
• HAZCHEM code and poisons schedule number
• physical description
• other properties
• ingredients
• health effects
• first aid
• advice to doctor
• precautions for use
• exposure standards
• engineering controls
• personal protection
• flammability
• storage and transport
• spills and disposal
• fire/explosion hazard
• other information
• contact point.

The conditional information may include telex and fax numbers. If information is not available about any of the issues shown as core

Case study 3.2

A railway workshop repairs bogies, the undercarriage pivots below the end of a locomotive. The workshop had been refurbished and the floor painted with an acrylic paint.

Workers were concerned that the repairing process (which required heating and cutting the bogie) would cause heated metal to fall to the floor and burn the paint, releasing unknown substances.

An occupational hygienist was called into the workshop to identify the type and airborne concentration of the substances to enable the risk to be assessed.
information, a statement will be made on the MSDS that the information was ‘not available’ or ‘not relevant’.

When identifying occupational hygiene hazards, all sections of the MSDS should be reviewed and checked against use in the workplace. For instance, is the substance being heated and does the MSDS describe any hazards that could be generated from heating?

**REVIEWING RECORDS — LABELLING**

A label is any information that identifies a substance. It also provides basic information about the substance’s safe use and handling. Again, as a first point of call, labels can assist in identifying occupational hygiene hazards at work.

For instance, the label may show the words ‘Class 8 — Corrosive’. This gives an indication about the physical nature of the substance and a small amount of interpretation would indicate the substance may cause burns.

There are many types of labels and regulatory requirements relating to information, size, colour and structure. Some examples of labelled substances include:

- agricultural and veterinary chemicals
- therapeutic goods
- foods and food additives
- cosmetics
- munitions
- explosives.

**SUMMARY**

Hazard identification or recognition is an important step in managing occupational hygiene risks. There are many techniques that can be used to identify hazards including discussions with workers and occupational health and safety professionals, occupational hygiene audits, walk-through surveys or inspections and personal experience and information sources.

**BIBLIOGRAPHY AND FURTHER READING**


Performance — Describing and Reporting Occupational Health and Safety Injuries (known as the National Standard for Workplace Injury and Disease Reporting), Standards Australia, North Sydney
Victorian WorkCover Authority 2000, SafetyMAP: Auditing Health and Safety Management Systems, 4th edn, Victorian WorkCover Authority
Airborne contaminants exist in a number of states. Dusts (or particulate) are a broad category that describes solid particles suspended in air. They may be mechanically or thermally generated and can affect different parts of the human body at work. Some inhaled dusts are removed from the body, although a fraction of these dusts will remain in the lungs without inducing a biological reaction. These are called nuisance dusts and their risk presents more as minor irritation or affecting vision. However, exposure to other dusts can lead to chronic lung disorders such as lung cancer, silicosis and bronchitis.

This chapter defines the terms respirable, inspirable and inhalable dusts, and describes occupational hygiene monitoring techniques to sample and analyse these contaminants in Australia. It also describes the physiological effects of exposure to dusts, particularly crystalline silica, asbestos, synthetic mineral fibres and wood dusts.

**DUST EXPOSURE IN INDUSTRY — A HISTORICAL REVIEW**

Exposure to dusts in the workplace has been occurring for a long time. Dust exists as a wide range of particle sizes. Mechanical actions such as grinding or crushing create dusts. Thermal energy applied to a solid such as metal generates fume. Fume consists of extremely small particles usually less than 1 micron (µm) in diameter.

Dust-related disease and ill health can be traced back to historical times. It was Hippocrates who identified that inhaled dust could affect health. From here, Charles Thackrah called attention to the effect of exposure to cotton and flax in the nineteenth century.

Coalmining in all countries has been associated with ‘dusty lung disease’, also known as coalworker’s pneumoconiosis or black lung, a progressive fibrosis of the lung. The term pneumoconiosis is derived from the use by Friedrich Albert von Zenker in 1866 of the term ‘pneumono koniosis’. Its application is now restricted to those diseases where silica has some implication.

Mining, quarrying and tunnelling through rock high in quartz containing a content of free silica has led to silicosis. Silicosis was usually accompanied by tuberculosis.

Stonemasons and those in the granite or stone carving industry often developed respiratory diseases. The consequence of exposure to asbestos dust is now showing its full effects, after latency periods of 30 to 40 years.

Even now, workers are exposed to dusts and fibres such as sensitising wood dusts, synthetic mineral fibres, organic dusts from the rural industry and crystalline silica.
DEFINITIONS

In the workplace, solid particles can exist as dust, fibre or fume. It is important to appreciate the fundamental differences between these states of matter (and their associated risk) to ensure they are correctly monitored and subsequently controlled. For instance, attempting to sample for thermally generated fume without identifying its exact nature may result in an unrepresentative concentration and indication of risk being made. Similarly, the highest risk of exposure to pesticides or herbicides can occur while mixing powders.

The following definitions are generally used:

- **Dust is a mixture of solid material of varying sizes.** Particles usually range in size from 0.1–30 µm. Examples include cotton dust from cotton milling and wood dust from sawmilling.

- **Fibre is a solid, thread-like filament with a defined length-to-width ratio.** The NOHSC (1988, p. ix) defines an asbestos fibre as having a diameter of less than 3 µm, length of more than 5 µm, and a length-to-diameter ratio of greater than 3:1. Other examples of fibres include fibreglass, rock-wool and ceramic fibres.

- **Fume is generated when a solid is heated until a gas is released.** The gas recondenses into minute solid or liquid particles.

DUSTS

Dusts can be described in terms of their physiological effect or the size distribution of the dust cloud. Fibrotic or fibrinogenic dusts are those that penetrate into the alveolar region of the lung and damage these cells, causing a scarring or fibrosis. Fibrotic dusts elicit this action deep in the lung because of their exceptionally small size and in some cases their composition (e.g. free silica {SiO₂}).

This is why fibrotic dusts are respirable, meaning that they enter the respiratory zone of the lungs. Respirability is defined according to a standard criterion. Some examples of fibrotic dusts include asbestos and crystalline silica, such as quartz or cristobalite.

Toxic dusts show their effect through the lung or other systems of the body. These outcomes might be an immunological response (e.g. exposure to sensitising woods like western red cedar or organic dusts) or a direct effect on an organ or system (e.g. slaked lime, calcium hydroxide, burning the skin or the eye).

Deposition of dusts in the lung

The passage of dusts in the human lung is dependent on their physical size and chemical composition. Large particles may not be able to penetrate past the upper respiratory system. Lever and Schroter (cited in Gardiner & Harrington 1995) believe there is a high probability that most particles with an aerodynamic diameter between 10 µm and 20 µm will impact in this region and will not penetrate to the airways of the lung. This is due to mechanical filtration through the nasal hairs, causing contaminants to be blown or sneezed from the nasal cavity. Smaller particles can enter the nasal cavity and become entrapped on the mucous-covered hairs within the cavity. At this point, certain water-soluble dusts such as potassium hydroxide (an alkaline dust) may dissolve in the mucous membrane and cause an irritating effect. Wood dusts also chiefly are filtered from the upper respiratory system; however, exposure to some hardwoods is reported to cause nasal cancer.

The major factor affecting the respirability of dusts is their ability to pass through the nasal cavity and reach the trachea. Larger
particles, due to their aerodynamic diameter, will impact on the rear of the nasal cavity and are unable to negotiate this steep turn.

The aerodynamic equivalent diameter (AED) of a dust relates to its physical diameter plus its density. The AED of selected dusts is shown in Figure 4.1.

The three chief mechanisms of particle deposition are:

- **sedimentation**
- **diffusion**
- **impaction**.

**Equation 4.1**

\[ v = \frac{\rho \cdot g \cdot d^2}{18 \eta} \]

Where:
- \( \rho \) is the particle density (kg.m\(^{-3}\))
- \( g \) is the acceleration due to gravity (9.8 m.s\(^{-2}\))
- \( d \) is the diameter of the dust particle (m)
- \( \eta \) is the viscosity of air (\( \approx 1.9 \times 10^{-5} \) N.s.m\(^{-2}\))

The gravitational force that a dust particle will exert affects the sedimentation velocity. The final sedimentation velocity (\( v \)) that a particle achieves is best described through Stoke’s law (Equation 4.1).

Using Equation 4.1, it can be seen that it is actually the particle density and diameter that affects the sedimentation velocity, providing air viscosity and acceleration due to gravity are constants. The density of an object (\( \rho \)) is defined as its mass per unit volume. The SI unit is kg.m\(^{-3}\). This relationship is shown in Equation 4.2.

**Equation 4.2**

\[ \rho = \frac{m}{V} \]

Where:
- \( m \) is mass (kg)
- \( V \) is volume (m\(^3\))

This means that denser particles will have a greater velocity, hence greater momentum or inertia. The increased drag of the air on the moving particle causes it to settle earlier. This...
philosophy can explain why fibres are airborne for a longer period than spherical particles and are hence more likely to be inhaled.

The degree of dust penetration can best be described by considering its linear momentum once it enters the nasal cavity. Momentum \( p \) is defined as the product of the dust’s mass and its velocity (Equation 4.3). Its SI unit is \( \text{kg.m.s}^{-1} \). The more momentum the dust has, the harder it is to stop and the greater the effect it will have if brought to rest by impact or collision. It therefore follows that a denser dust will have a greater momentum at a constant velocity than a less dense dust.

\[
\text{Equation 4.3} \quad p = mv
\]

Where:
- \( m \) is mass (kg)
- \( v \) is velocity (m.s\(^{-1}\))

Dusts with a smaller physical diameter, or which are less dense, will be able to travel through the nasal cavity, negotiate the sharp turn at the nasopharyngeal region and pass into the trachea. The entrained dust can then continue to move through the primary bronchus, through the bronchi and bronchioles and into the air-exchange sacs, the alveoli.

Diffusion will also affect the time available for deposition of the dust. Since airborne dusts consist of gas molecules that are constantly moving, particles may be carried along with the airflow and deposited in the respiratory tract.

Impaction is the final factor that affects the deposition of particles in the respiratory system. Although particles are entrained in a gaseous medium, they have a much greater momentum and hence inertia than gas. Therefore, as the airflow direction changes to negotiate its way through the respiratory system, the dust particles are unable to adapt to the change and keep moving in the same direction. If the momentum of the particles is enough, they will impact on the curved airways and nasal hairs.

**The alveolar region and dust removal**

Alveoli are tiny depressions along the walls of alveolar sacs. The alveolar sacs resemble bunches of grapes, where the flesh of the grape is the gas-filled alveoli. The walls of the alveoli consist of a single layer of cells that are covered with a network of capillaries. As air (and its contaminants) passes into the alveoli, gas exchange occurs by simple diffusion across the alveolar wall and into the blood. If respirable dusts move into the alveolar region of the lung, they are not transferred across the capillary barrier. Instead, the body uses non-specific cellular and chemical defences to remove these foreign particles.

Phagocytosis is the term given to the ingestion of a micro-organism or particulate matter by a cell. The cells that produce this function are white blood cells or their derivatives such as macrophages or neutrophils. Phagocytosis can be divided into the following four phases:

1. chemotaxis
2. adherence
3. ingestion
4. digestion.

Phagocytes are firstly attached to the foreign dust particles. This is called chemotaxis. The plasma membrane of the phagocyte then adheres to the surface of the dust. Phagocytes find it easier to attach to dusts with a rough surface. Ingestion of the dust then occurs. In this process, the phagocyte, in a sac called a phagocytic vacuole, surrounds the dust. The final phase of digestion occurs where digestive enzymes and bacterial substances from lysosomes break down the dust. At this point,
the phagocytic vacuole and lysosome membranes fuse to form a single structure, the digestive vacuole. Once digestion is complete, the digestive vacuole discharges the wastes (Figure 4.2).

Some dust particles (e.g. crystalline silica and asbestos) cannot be destroyed by phagocytosis. Asbestos fibres in the alveolar region can become coated with layers of iron-containing protein. These are known as asbestos bodies. Exposure to crystalline silica is believed to damage the alveolar macrophages and damage the lysosome membrane, causing the death of the macrophage. These cells then calcify and join to form nodules. The nodules grow and coalesce, reducing the area of lung tissue available for oxygen exchange. As this occurs, the lung tissue loses elasticity and fibrotic tissue is formed.

Occupational asthma has been reported from dust exposure to substances such as grains, tea, bagasse (a by-product of sugar milling) and high-molecular weight animal proteins. The effects are believed to be an immunological response to these allergens. Chronic respiratory symptoms also affect textile workers exposed to hemp and cotton. A comprehensive discussion about the source and health effects of organic dusts can be found in Chapter 10.

**SIZE DISTRIBUTIONS OF DUSTS**

We have already said that occupational dusts can be classified according to their size and chemical composition, and that their size refers to the AED. Dust clouds do not exist uniquely as one size but as a range of compositions instead. This is termed the size distribution.

The three size distributions of occupational significance are:

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Figure 4.2 Phagocytosis
• respirable dust
• inspirable (inhalable) dust
• total dusts.

Respirable dusts consist of tiny particles that are able to penetrate into the alveolar region of the lung and show an effect there. Inspirable (also called inhalable) dusts have a larger AED and hence settle higher in the respiratory system. The term total dust generally has limited application in occupational hygiene, as it refers to all dusts whether they are inhalable or not.

**Respirable dust**

The size distribution of respirable dusts is defined according to the British Medical Research Council (BMRC) curve or the Johannesburg curve (Figure 4.3), although most countries are moving to the criteria defined by the International Standards Organisation (ISO).

The BMRC curve plots the AED against a percentage of respirability. Figure 4.3 shows that particles with an AED less than 1 µm are 100 per cent respirable. Notice that as the AED
increases to 5 µm, the particles are defined as 50 per cent respirable; and above 7 µm, particles have no penetration to the respiratory zone of the lung.

Some examples of dusts that show their effects in the alveolar region of the lung include:

- **crystalline silica** (e.g. quartz, cristobalite, tridymite) generated during quarrying, mining or sandblasting
- **asbestos** (e.g. chrysotile, crocidolite, amosite) used in brake linings, textiles and lagging due to their thermal insulation properties; however, while asbestos is respirable the definition of a countable fibre does not conform to the BMRC curve (this is discussed shortly)
- **vanadium dust or fume**, resulting from use as an alloy for **strengthened steel** and more recently in trial tests of vanadium batteries.

**Inspirable (inhalable) dust**

Over the past years, discussion has continued with regard to the definition of inspirable or inhalable dusts. This discussion has resulted in agreement that the ISO Mass Fraction Sampling Curve should be adopted, defining such dust as inhalable. Currently, Australia still uses AS3640 as a reference to describe how to sample and gravimetrically analyse inspirable dust. From this, it provides the following alternative (although philosophically similar) criteria to define inspirable dusts:

- **inspirable mass fraction**, by the ISO
- **inspirable mass sampling efficiency**, from the ACGIH.
Each curve plots inspirability against the particle AED. Figures 4.4 and 4.5 show the ISO and ACGIH criteria, respectively. However, it should be noted that the new ISO criterion is now the agreed criterion for inspirable dusts.

The ISO inspirable mass fraction defines all particles with an AED of less than 0 µm to be 100 per cent inspirable; at 30 µm, they are around 52 per cent inspirable; and above 185 µm, the particles are not inspirable. This compares with the ACGIH curve, which corresponds to the ISO inspirable mass fraction criteria at 0 µm but allows particles with an AED of 30 µm to have a 58 per cent inspirability. At 50 µm, the ACGIH criteria specifies such particles are 50 per cent inspirable; however, at 185 µm, the curve does not define a level of inspirability.

The difference in definitions of inspirability need not have a significant effect on the overall approach to inspirable dust monitoring. However, if the dust cloud to be sampled has a higher proportion of larger particles (>30–50 µm), the ACGIH definition may give higher results, compared to the ISO criteria. With the new adoption of the ISO criteria by most countries, this point will be defunct.

The following list shows some examples of inspirable dusts:

- birch or beech timber used for housing construction and finishing
- cement dust from concreting work
- metal dusts such as zinc oxide from grinding galvanised steel.

**Total dusts**

Total dusts have little occupational hygiene significance and should not be monitored in the workplace, except where the distribution of the dust cloud is sought.
RESPIRABLE DUST MONITORING

Respirable dust can be monitored in Australia by following AS2985. Determining the concentration of respirable dust is a two-stage process, namely sampling for respirable dust using a size-selective monitoring device, and analysing the sample gravimetrically (by weight) or chemically (looking for a specific analyte).

By itself, respirable dust concentration has little occupational relevance. The NOHSC has not prescribed an occupational exposure standard for respirable dust per se, except for coaldust containing less than 5 per cent quartz. For this, a TWA of 3 mg.m$^{-3}$, measured as the respirable fraction, has been designated. This means that the sampled respirable dust may need to be analysed to quantify the exact amount of specific analyte, for instance quartz, cristobalite or tridymite (all forms of crystalline silica).

In some Australian States and Territories, a respirable dust TWA has been specified by the regulatory authorities.

In order to compare respirable dust samples with NES, the sample must be collected in the breathing zone. The components of the sampling system (sampling train) will include:

- a filter to collect the sample
- a holder to prevent air from leaking around the side of the filter
- a size-selective sampling device that conforms with the BMRC deposition curve
- a sampling pump
- flexible tubing to connect the pump to the sampling device
- a device for calibration
- a belt for connection of the sampling pump to the worker
- a time measurement device.

Filters

Filters can be made from a variety of media. The decision on the type of filter that is selected for respirable dust monitoring will depend on the analytical technique required and characteristics of the filter that make it appropriate for use. For instance:

- sampling air through PVC and polycarbonate filters can create an electrostatic charge that may affect the dust loading and adherence of dust to the filter
- silver membrane and fibreglass filters can lose mass
- mixed cellulose ester (MCE) filters are hydrophilic and gain weight by absorbing water vapour from the sampling environment
- filters that are ashed (burned) before analysis must be appropriate for this type of analysis.

Filters also have a nominal pore size. This relates to the space between fibres of the filters. Respirable dust sampling requires the use of filters with nominal pore sizes of 5 µm or less. However, where polycarbonate filters are used, the nominal pore size must be 0.8 µm. The diameter of the filter must also be consistent with the sampling device. For respirable dust sampling, the diameters are typically 25 mm or 37 mm.

Size-selective sampling devices

Filters are fitted into a sampling device that conforms with the BMRC curve.

These include the British Cast Iron Research Association (BCIRA) (Higgins and Dewell) cyclone elutriator and Simpeds (Safety in Mines Research Establishment) cyclone elutriator. SKC also manufactures a plastic cyclone elutriator, which is commonly used in Australia.
Figure 4.6  Principle of operation of the cyclone elutriator

Figure 4.7  Weighing filters on a microbalance
Cyclone elutriators operate on the principle of centrifugal impaction of dusts. Dust-laden air enters the inlet and is circulated in a centrifugal motion into the cyclone (Figure 4.6).

Dust particles whose AED conforms to the BMRC curve impact on the filter. Larger particles have too much inertia and will fall into the grit pot at the base of the cyclone. The grit pot should be regularly cleaned to remove these larger non-respirable particles.

Such devices are loaded by firstly weighing the appropriate filter before loading it in a cassette and the cyclone elutriator. The filter should be weighed using a microbalance that is capable of weighing to within 0.01 mg at the 90 per cent confidence level in the range 0–20 mg. This is shown in Figure 4.7.

The filters should be placed above a static eliminator to dissipate any electrical charge before weighing. It is important not to place the filter directly over the static eliminator, since it is usually an alpha (α) particle source and may result in minute holes in the filter.

Filters should be left in a constant environment, such as a balance room, at least overnight to allow them to come to equilibrium. In addition to the sampling filters being weighed, 10 per cent of weighed filters should be kept as blanks, with a minimum of two blanks per batch of weighed filters. Blanks are an example of an internal quality check that can be used to correct any changes in the mass of the filters.

**Calibration of the sampling train**

Once the weighed filters are loaded into the cyclone elutriator, the entire sampling train is calibrated accurately at 1.9 L.min$^{-1}$. The sampling train consists of the pump, tubing, filter and cyclone elutriator. This can be conducted using a primary flow meter such as
a soap-film flow meter or with a secondary flow meter that has been calibrated against a primary flow meter. In the field, it is often not convenient to utilise a primary flow meter so a secondary meter such as a ball rotameter can be used (Figure 4.8). Whatever technique is being used, the calibration technique must be sensitive enough to measure within ±5 per cent variation of flow rate.

Sampling for respirable dust must be conducted over a period of at least four hours but should be representative of the actual working shift and as long as practicable. The sampling procedure will involve the following steps:

- **Attach the sampling pump to the belt of the worker** (or in their close vicinity, for instance, if the worker is driving a vehicle and the placement of the pump on the belt is uncomfortable).
- **Attach the loaded cyclone elutriator within the breathing zone of the worker**, ensuring that the cyclone elutriator is kept upright during the sampling to prevent dust from falling from the grit pot of the cyclone elutriator.
- **Record information about the worker and the sampling equipment.** This will include the cyclone identification, filter identification, pump identification, date of sampling, time of pump starting, initial flow rate, worker’s name or other identifier, description of work or task, controls and environmental conditions and other relevant data. The sample is then collected during the shift. It is prudent to check the calibration of the sampling train during the shift as the flow rate can be affected by issues such as pump charge, loading of the filter and backpressure placed on the pump.

- **Once sampling has been completed,** the flow rate is re-checked before switching off and removing equipment from the worker.

The final flow rate must not differ by more than 5 per cent of the initial rate or the sample will need to be rejected and re-collected. The cyclone elutriator or cassette should then be isolated from other samples in a dust-free box. Some cassettes contain clips that allow the inlets to be closed to prevent further dust from contaminating the sample.

**Determining the mass of respirable dust**

Once sampling has been completed, the sampled filters and blanks are re-weighed after another period of allowing the filters to come to equilibrium in a stable environment. Some hydrophilic filters such as mixed cellulose ester will absorb water vapour from the air and hence may be heavier following sampling. The electrostatic eliminator is also used again to dissipate any charge before re-weighing.

**Equation 4.4**

$$m_{\text{final}} = m_{\text{initial}} \pm m_{\text{blank}}$$

Where:
- \(m_{\text{final}}\) is the mass of dust collected on the filter (mg)
- \(m_{\text{initial}}\) is the initial mass of the filter
- \(m_{\text{blank}}\) is the difference in mass of the blank filter.

The mass of dust collected on the filter can be determined using Equation 4.4. With the blank filter, a gain of mass between the two monitoring periods requires an adjustment to the overall mass by subtracting this from the total mass. If the blank filter loses mass, this amount is added to the final mass of the sample.
Example 4.1
A 37-mm filter (filter A) had an initial mass of 11.367 mg. The initial blank filter had a mass of 11.523 mg. Following sampling, filter A was found to weigh 13.112 mg and the blank was 11.533 mg. What is the mass of the sample in mg?
Answer:
The actual mass of the sample would be:
13.112 – 11.367 – (0.01) mg = 1.735 mg

Determining respirable dust concentration

Concentration is expressed as a mass (mg) per unit volume (m$^3$) of sampled air and is shown as Equation 4.5.

Equation 4.5
\[ c \text{ (mg.m}^{-3}\text{)} = \frac{\text{mass of sample (mg)}}{\text{volume of sampled air (m}^3\text{)}} \]

The mass can be simply obtained from the gravimetric determination of the dust, after taking into account any difference with the blanks. The volume can be calculated using Equation 4.6.

Equation 4.6
\[ V \text{ (m}^3\text{)} = \frac{[\text{flow rate (L.min}^{-1}\text{)} \times \text{duration of monitoring (min)}]}{1000} \]

Where further chemical analysis of the sampled dust is conducted, its concentration may still be determined using Equation 4.5, although the mass of analyte will be not merely assessed gravimetrically. Example 4.2 shows application of this theory.

Example 4.2
Respirable dust sampling was conducted over 8 hours. The calibration of the sampling train was checked before and after sampling and found to be 1.9 L.min$^{-1}$. The mass of the sample on the filter was found to be 3 mg. What is the concentration of respirable dust?
Answer:
Solve for c using:
\[ c \text{ (mg.m}^{-3}\text{)} = \frac{\text{mass of sample (mg)}}{\text{volume of sampled air (m}^3\text{)}} \]
To determine volume (V):
\[ V = \frac{[1.9 \text{ L.min}^{-1} \times 480 \text{ minutes}]}{1000} = 912 \text{ L} = 0.912 \text{ m}^3 \]
Solve for c:
\[ c = \frac{3.0 \text{ mg}}{0.912 \text{ m}^3} = 3.3 \text{ mg.m}^{-3} \]
Note that the results are reported to one decimal place, with no more than two significant figures.

INSPIRABLE DUST MONITORING

Monitoring for inspirable dust follows the same principles as respirable dust monitoring. An airborne sample of a known substance is collected in the breathing zone, using a size-selective sampling device that is connected to a sampling pump. AS3640 describes the technique for sampling and gravimetric analysis of inspirable dust. With this method, the chosen sampling device must have a sampling efficiency that conforms to the ISO or ACGIH criteria.

The two common devices used for this purpose are the IOM open-face sampling head, and the UKAEA 7-hole sampling head. An alternative sampling head used for sampling inspirable metals, the single-hole sampler, is discussed in Chapter 5.
Both sampling heads are loaded with a pre-weighed filter prior to sampling. The filter is held inside the sampler on a gridded supporting base. When assembling the sampler, it is vital that the filter is handled carefully with tweezers and not with the fingers. This will minimise the chance of contamination of the filter. Once loaded, the sampler is reassembled and firmly tightened to stop leakage. (Note, however, that excessive tightening may cause the enclosed filter to tear, resulting in an invalid sample.) The sampling head is usually located on the lapel of a worker’s shirt, in a vertical position. If it is allowed to lie horizontally, gravitational settling of dust will affect the integrity of the sample. According to AS3640, both the IOM and UKAEA sampling devices are calibrated in the sampling train at a flow rate of 2.0 L.min\(^{-1}\). The train must be calibrated before and following sampling, and be within ±5 per cent. For further detail about the technique for calibration, selection of filters and determining the mass and concentration of inspirable dust, the principles outlined in the section on respirable dust monitoring apply. Depending upon the composition of dust being monitored, the sampled filter may be analysed gravimetrically or sent to a laboratory for analysis.

TOTAL DUST MONITORING

Total dust monitoring has traditionally been incorporated into some mining regulations and is used by some US-based companies in Australia. The open- or closed-face cassette was developed and is used in the US. Unfortunately, the sampling efficiency of these devices does not closely reflect the criteria of AS3640. They tend to under-sample the inspirable fraction. For this reason, total dust monitoring is being rapidly phased out and the results must not be compared with the NOHSC inspirable dust standards.

These cassettes consist of two or three stages (housings) and can collect a dust sample either with the face of the sampler open or closed. If closed, the sample is collected through an inlet. The filter is held firmly between the stages. Depending on the dust to be collected, the filter may be washed or pre-treated in a chemical solution before sampling. However, the advantage of these cassettes lies in their limited reactivity with collected substances, for instance, alkaline dusts. Sodium hydroxide, calcium carbonate and calcium hydroxide can be monitored using this technique.

PARTICLE SIZE AND DUST CHARACTERISATION MONITORING

As already mentioned, total dust measurements hold no value in assessing the risk to workers’ health. However, in limited situations a sample of total dust may be taken to determine its constituent particle size range. A cascade impactor is a useful sampling device for this purpose. The first cascade impactor was developed in the mid-1940s. The principle of operation of cascade impactors is to draw air through the sampler, which contains several levels or orifices in series. As the air passes deeper into the sampler, it speeds up. Using a similar principle to the cyclone elutriator, the large particles impact on a collection media (e.g. a filter). The filters are pre-weighed before sampling and re-weighed after use. Smaller particles continue to move through the impactor until their inertia also causes them to come to rest on the media. Each level or stage represents a particular size range. Therefore, in effect, the cascade impactor separates the dusts into fractions.

The Andersen sampler is a common example of this type of impactor. After entering the initial circular orifice of the Andersen sampler, the air passes through a
series of perforated circular plates. Subsequent plates in the series have smaller holes. So, the larger particles are deposited towards the top of the impactor and the smallest particles deposit further down.

Several stages are available with these samplers, the most common of which are cascade impactors with four, six or eight stages. The different size fractions can then be examined for specific mineral content, particle shape or chemical content.

**DIRECT-READING MONITORING EQUIPMENT**

The dust sampling techniques discussed so far have focused on sample collection and analysis. However, the application of these methods is often limited by the time taken for sample collection, transportation to a laboratory and analysis of filters. To assist in the initial identification of dusts as a potential risk to workers, direct-reading monitoring equipment can be invaluable. These devices provide a real-time measurement of dust exposure according to a specified size criterion.

The disadvantages of using direct-reading monitoring equipment include:

- cost of purchase and maintenance
- calibration requirements for some devices and lack of calibration of others
- conformance with an acceptable dust size criteria.

The principles of operation of these devices are quite distinct and include:

- light attenuation or scattering
- using the electrical properties of the dust
- mass of the dust
- beta-attenuation of radiation by the collected dust.

Light scattering or optical monitors relate the intensity of scattered light to particle concentration. As dust enters the monitor, it causes the light to be extinguished or scattered. The disadvantage with these types of devices is their lack of pump. This means that the dust must be able to enter the monitor without mechanical means. These types of monitors also rely on the relationship between particle size and light scattering response. This means that the results may be difficult to interpret unless the size response has been determined. The US-developed real-time aerosol monitor (RAM), or its smaller version the MiniRAM, is often used in an initial dust survey. The MiniRAM has the advantage of collecting a sample in the breathing zone of the worker due to its smaller size and the response of the monitor corresponds reasonably with the respirable dust criteria. The MiniRAM is currently being replaced by a personal dust monitor. Another brand, the Hund monitor, also produces a similar response.

Monitors that determine dust concentration using the electrical properties of the dust work by counting and sizing the individual dust particles. An example of this is the fibrous aerosol monitor (FAM), which counts respirable fibres. A mass-measuring device actually assesses the mass of certain dusts by comparing it against its mechanical oscillation of a piezoelectric crystal. As the crystal is bombarded with dust, its mass changes and this is converted into a change in its mechanical resonant frequency.

**DUSTS OF OCCUPATIONAL HYGIENE SIGNIFICANCE**

This section provides an overview of some dusts that may, depending upon exposure, represent a risk to workers’ health. As previously discussed, risk is related to the exposure duration, frequency and severity of
outcome. It is also linked to the perception of the hazardous nature of exposure and whether or not the risk is tolerable.

**Silicaceous dusts**

Silicon is one of the most widely spread elements on earth. Indeed, the majority of the rocks in the earth’s crust are silicates. The term silicate refers to compounds that are bound with silicon. Silicon dioxide (SiO$_2$) or silica is the simplest form of silicon compounds. It is also potentially hazardous, depending upon its physical configuration. Other types of silicates include naturally occurring minerals such as:

- **asbestos** (used in building materials and for fireproofing)
- **clay minerals such as bauxite**
- **feldspar** (a pottery glaze and abrasive material)
- **garnet** (a precious stone for jewellery, also used as an abrasive blasting medium)
- **magnetite**
- **mica** (has application as an electrical insulator)
- **olivine** (used as an alternative sand to free silica in foundry operations)
- **portland cement** (used for making concrete and mortar)
- **soapstone** (also known as massive talc or steatite)
- **talc** (a fine dust used in cosmetics, crayons and wallpaper)
- **vermiculite** (for paints and insulation).

These silicate minerals are actually the combination of silicon and oxygen atoms with other metals such as magnesium (Mg), iron (Fe), aluminium (Al), calcium (Ca), sodium (Na) and potassium (K). Asbestos is discussed in further detail as a fibre later in this chapter. Mica has the approximate formula KAl$_2$(AlSi$_3$O$_10$)(OH)$_2$ and a TWA of 2.5 mg.m$^{-3}$ (inspirable fraction). The mineral olivine has the approximate chemical configuration of MgFeSiO$_4$ (inspirable fraction). Portland cement is formed from a mixture of calcium silicate and aluminate. It has a TWA of 10 mg.m$^{-3}$, measured as the inspirable fraction. Concrete is a mixture of cement, sand and a filler such as crushed stone. Mortar combines cement, sand and usually slaked lime, Ca(OH)$_2$. The significance of slaked lime is described later. Soapstone, (MgO)$_2$(SiO$_2$)4H$_2$O, with less than 1 per cent quartz and no asbestos, has a TWA of 6 mg.m$^{-3}$ as inspirable dust. Talc has the composition Mg$_2$Si$_2$O$_5$(OH)$_2$ and has a TWA of 2.5 mg.m$^{-3}$. Silicon carbide (SiC) is an example of silicon-based carbides, which are used as an abrasive in grinding wheels. Its TWA is 10 mg.m$^{-3}$ (inspirable dust).

**Silicon dioxide (silica)**

Silicon dioxide (SiO$_2$) or silica is the simplest of silicon compounds. From an occupational hygiene perspective, the major risk to workers’ health can be determined by considering its physical structure. Silica exists in two forms: crystalline (free) and amorphous (non-crystalline). Crystalline silica is further divided into five different symmetrical configurations or polymorphs.

**Crystalline silica**

Quartz is the most commonly found form of silica that is stable at ordinary temperatures. It is widely distributed in the natural environment and occurs in granite (an igneous rock), gneiss and mica (metamorphic rocks), and sandstone and quartzite (sedimentary rocks). It is also the main constituent of sand. Sand can be utilised in glassmaking, as an abrasive blasting medium, in metal polishing and as a water filter in swimming pools. Silica mining is another potential source of exposure. The NOHSC exposure standard for quartz is 0.2 mg.m$^{-3}$, expressed as the TWA. Cristobalite, another form of crystalline
silica, is stable at high temperatures. It is formed by heating quartz well above 1150°C. While cristobalite is found less frequently in the workplace, it does present a greater risk to workers. The TWA for cristobalite is 0.1 mg.m\(^{-3}\).

Heating crystalline silica between 870°C and 1470°C also produces tridymite (although it is unlikely this occurs in industry). Tridymite has a TWA of 0.1 mg.m\(^{-3}\). The final two types of crystalline silica are stishovite and coesite. Heating quartz at very high temperatures and pressures forms both of these.

All polymorphs of free silica are monitored as the respirable dust fraction, according to AS2985. The industries or tasks where exposure to free silica is most prevalent include:

- **quarrying, metalliferous mining and coalmining** (coal seams often contain a small amount of SiO\(_2\))
- **abrasive blasting** where silica sand is used as the medium
- **stonemasonry** (grinding and chipping of sandstone or other stone containing crystalline silica)
- **concrete manufacture and use**
- **foundry operations** where the moulds are made from silica sand.

**Amorphous silica**

The characteristic of amorphous silica that differentiates it from crystalline silica is its random arrangement of silicon and oxygen atoms. Some examples of amorphous silica include:

- **diatomaceous earth** (used to absorb liquids, for lagging steam pipes and as a component of dynamite) — uncalcined diatomaceous earth has a TWA of 10 mg.m\(^{-3}\), measured as the respirable fraction; however, if calcined (heated above 1150°C), it may contain a significant proportion of crystalline silica and exposure must be kept below the relevant national exposure standard for free silica
- **fumed silica**, which has a TWA of 2 mg.m\(^{-3}\) and is measured as the respirable fraction
- **precipitated silica**, a largely nuisance dust that is deposited in the upper respiratory tract — it has a TWA of 10 mg.m\(^{-3}\), measured as the inspirable fraction
- **silica gel**, a hydrophilic substance that is used to reduce humidity — it is fairly innocuous and has a TWA of 10 mg.m\(^{-3}\) (inspirable dust).

**Sampling and analysing for siliceous dusts**

The choice of sampling technique for siliceous dusts will depend upon whether they affect the upper respiratory system or deep into the alveolar region of the lung. Sampling and analysis of some inspirable dusts such as silicon carbide can be conducted according to AS3640 using gravimetric analysis. Other inspirable siliceous dusts may be sampled using the method described in AS3640, although further chemical analysis of the sample may be required to identify individual constituents. For instance, the mass of talc or mica is determined gravimetrically and then the filter is analysed using a technique called X-ray diffraction.

The polymorphs of crystalline silica are monitored as the respirable dust fraction, according to AS2985. Once sampling has been completed, the mass of respirable dust can be determined using gravimetric analysis. The filter is then analysed for specific polymorphs (commonly quartz or cristobalite) either directly or after the filter is ashed (destructed by heating). The two methods available for determining the nature and quantity of respirable quartz are infrared (IR) spectroscopy and X-ray diffractometry (XRD).
XRD is based on the principle of light beams diffracting (reflecting) from the planes in a three-dimensional crystal. It is used to quantify both quartz and cristobalite. IR spectroscopy (or spectrophotometry) can identify specific pure substances, especially organic compounds and covalently bonded metal complexes. Different types of crystalline and amorphous silica have specific fingerprints or patterns, depending upon their structure. For direct measurement, the collected sample-on-filter is placed in the line of the infrared beam, while a blank filter is placed in front of a reference beam. Since quartz has a double peak (a doublet) at 798 cm$^{-1}$, the plot of transmission versus wave number will show this distinct characteristic.

If measurements cannot be directly measured from the filter, it can be heated and formed into a potassium bromide (KBr) disc. Since the quartz absorbs infrared radiation, the transmission will change at varying frequencies. This method will utilise blank KBr discs, and the doublet at 798 cm$^{-1}$ is expected for quartz.

The standard method for this analytical technique is the National Health and Medical Research Council (NH&MRC) Methods for Measurement of Quartz in Respirable Airborne Dust by Infrared Spectroscopy and X-ray Diffractometry. Laboratories that perform analysis for quartz are usually National Association of Testing Authorities (NATA) accredited.

**Health effects from exposure to crystalline silica**

Exposure to free silica is known to cause a fibrotic pneumoconiosis called silicosis. Silicosis is also known as grinders’ rot, masons’ disease, miners’ phthisis and potters’ rot. The magnitude of the risk is associated with the physical structure of silica, so non-fibrous silicates are less likely to harm the lungs. With free silica, freshly generated dust is of higher risk than old dust.

Silicosis often is not accompanied by significant clinical symptoms. However, a chest X-ray will show calcification in the lung. These lesions are made up of nodules, composed of connective tissue, coalescing to form masses. Simple or uncomplicated silicosis does not usually cause premature death, although in some people the disease progresses to acute silicosis. In the lung, the acidity of lysosomes in the macrophages can usually etch or dissolve the free silica. However, if the macrophages are overloaded they may die, causing the tissue coalescence to form nodules, which are seen on a lung X-ray. This scarring leads to an area in the lung that is no longer functional as a gas-exchange region.

With acute silicosis, the alveolar spaces become filled with a fluid. Symptoms develop quickly. The disease is usually fatal within a year of the first symptoms. It is important to note that acute silicosis is relatively rare, and has been associated with short-term exposure to dusts containing a high concentration of quartz.

**Carbon-based dusts**

Exposure to carbon at work occurs either through pure carbon or carbon fixed to other elements as carbonates or hydrides. Pure carbon exists as two main forms: graphite and diamond. Graphite is a grey, greasy substance that conducts electricity well and is used as a dry lubricant and to manufacture brushes for electric motors. Its TWA is 3 mg.m$^{-3}$, measured as respirable dust. Diamond is used in the industrial setting for drills and abrasives, due to its incredible strength and hardness.

Charcoal is often referred to as amorphous carbon, since it is a microcrystalline form of graphite. Carbon black is a commercial form of carbon used in inks and as filler for rubber. Its TWA is 3 mg.m$^{-3}$ (respirable dust).
Carbonates

Carbonates are formed as a result of the reaction between carbon dioxide (CO\textsubscript{2}) and a strong alkali such as sodium hydroxide (NaOH). Chalk and limestone (CaCO\textsubscript{3}) are examples of carbonates. Additional information about these and other alkali dusts is included later in this chapter. Carbonates are used in industry for:

- **buffering chemical reactions**
- **manufacturing cement and as an aggregate for concrete**
- **manufacturing glass**
- **as a filler for rubber**.

Sodium carbonate (Na\textsubscript{2}CO\textsubscript{3}) is another form of carbon. It is a component of washing detergent and softens the water. Sodium hydrogen carbonate (NaHCO\textsubscript{3}) is also known as bicarbonate of soda and is used in cooking.

Coal

Coal is a naturally occurring solid that is found in deposits particularly in Queensland, New South Wales and Victoria. It can be mined: either through open-cut techniques where the topsoil layers (overburden) are removed and the coal extracted methodically; or, if the deposit is too far beneath the earth surface, it can be extracted from underground. Underground coalmining has the potential to generate considerable amounts of coaldust due to the process of cutting and removal.

Exposure to excessive levels of coaldust can lead to a lung condition known as coal workers' pneumoconiosis or 'dusty lungs'. It presents as lesions on the lung tissue, especially in the upper region of the lung. The condition may progress no further than this initial simple pneumoconiosis stage. However, the disease may progress to progressive massive fibrosis (PMF). PMF is characterised by large black, fibrotic masses containing coaldust and collagen fibres in the upper and middle sections of the lungs. Both simple pneumoconiosis and PMF cause a decrease in the vital capacity of the lungs. The vital capacity refers to the total amount of exchangeable air. Some studies link exposure to coaldust with the development of emphysema. The current TWA for coaldust containing less than 5 per cent quartz is 3 mg.m\textsuperscript{-3}, measured as respirable dust. If the coal does contain more than 5 per cent quartz, monitoring should ensure that the concentration of quartz is determined, in addition to coal. Sampling should be conducted according to AS2985.

Wood dusts

Occupational hygiene monitoring for wood dusts should be performed according to AS3640, since it is the inspirable fraction that presents a health concern. The samples can be analysed gravimetrically. However, the difficulty lies in its interpretation with national exposure standards. The NOHSC divides wood dust exposure into two groups: hardwood and softwood. Hardwoods can be broadly thought of as those which derive from deciduous, broad-leaved flowering species, in the botanical group angiosperm, for instance, eucalyptus, teak and silky oak. Softwoods are usually conifers such as pine and are categorised under the botanical group gymnosperm. In Australia, the TWA for certain hardwoods is 1 mg.m\textsuperscript{-3}. This is based on the potential for adenocarcinoma. Certain types of hardwoods are also sensitisers (e.g. western red cedar). For softwoods, both a TWA and STEL have been specified as 5 mg.m\textsuperscript{-3} and 10 mg.m\textsuperscript{-3}, respectively. This section of this chapter will discuss the health effects from exposure to wood dust. As such, it will not address the chemical hazards associated with reconstituted wood products such as particleboard, plywood and medium density wood.
fibreboard (MDF). This discussion can be found in Chapter 6.

The major health effects from exposure to wood dusts are broadly divided into:

- **toxic effects** due to release of alkaloids and other organic compounds
- **carcinogenic effects (nasal cancer)**
- **allergic responses** such as dermatitis or respiratory sensitisation
- **irritation**.

It therefore follows that the industries most at risk of exposure to wood dust are those in timber furniture manufacture, sanding of timber floors of homes or buildings, construction work and (to a lesser extent) hardware outlets.

Exposure to hardwoods (and some softwoods) is believed to cause nasal cancer. However, the latency period is often 30 to 40 years, thus the full magnitude of its effects are still largely unknown. Exposure to wood dust can cause a respiratory response and dermatitis. The allergic respiratory response is usually an immunologically mediated reaction to the allergen (hypersensitivity). Western red cedar is acknowledged as causing occupational asthma. Exposure of the skin to the dust may result in dermatitis, either from the mechanical action of dust against the skin, chemical irritation from the rosin and oils in the wood or sensitisation.

Non-allergic or irritation effects relate to the impact of dust on the respiratory system, especially in the reduction of ventilation capacity associated with exposure to wood dusts. It is also suspected that wood dust can cause an increase in upper respiratory tract symptoms to the nasal region, such as rhinitis.

### Alkaline dusts

This category of dust is really describing a type of inspirable dust. However, it does have specific chemical characteristics that make it worthy of mention. Alkaline dusts (or bases) have a pH of more than 7. They can be used in processes to maintain acidity balance and as filters, alloys in lead production and cleaning

<table>
<thead>
<tr>
<th>Table 4.1 Some alkaline dusts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alkaline dust name</strong></td>
</tr>
<tr>
<td>calcium carbonate</td>
</tr>
<tr>
<td>calcium hydroxide</td>
</tr>
<tr>
<td>calcium oxide</td>
</tr>
<tr>
<td>potassium hydroxide</td>
</tr>
<tr>
<td>sodium hydroxide</td>
</tr>
</tbody>
</table>
agents. Some examples of alkaline dusts and their exposure standards are shown in Table 4.1.

These dusts are chemically reactive, which caused problems when monitoring them with an open-face plastic cassette; however, the SKC IOM sampler has now removed this problem. If using the open-face plastic cassette (which is the least preferred method), a pre-treated (acid-washed) filter is loaded into the cassette. Once sampling is completed the filter is chemically analysed. Since there is no recommended Australian standard for analysis of alkaline dust, NIOSH Method 7401 is an option. It is suitable for monitoring of dusts such as sodium hydroxide and potassium hydroxide. Calcium-based substances such as calcium carbonate, calcium oxide and calcium hydroxide can be monitored using NIOSH Method 7020 as a guide.

**Organic dusts**

Organic dusts can be defined as those from an organism containing carbon. This section focuses on dusts (particularly from rural workplaces) as opposed to microbiological contaminants, which are detailed later in Chapter 10. The major outcome from exposure to organic dusts is usually irritation; however, some individuals have an immunological response. For instance, cotton, flax, hemp and sisal dusts can cause irritation and an allergic lung disease known as byssinosis. Workers at risk include those involved in textile manufacture, cotton farming and ginning.

The disease begins as an obstructive airway disease, which progresses to irreversible damage of the lungs. The monitoring technique is similar to that of the US cotton industry. This technique utilises neither the respirable nor inspirable size fraction criteria. A vertical elutriator is used for the purpose. The TWA for raw cotton dust is 0.2 mg.m$^{-3}$.

Other organic dusts of occupational hygiene significance are:

- tobacco
- starch
- sucrose
- cellulose
- grains.

The health effects of exposure to these dusts are both irritant and, in some individuals, immunological in nature, largely due to the dusts’ high molecular weight. For instance, confectionery workers are reported to have a decrease in pulmonary function and this is related to exposure to sucrose.

**Nuisance dusts and dusts not otherwise classified**

A category called nuisance dusts, or dusts not otherwise classified, exists for dusts whose effect is more due to discomfort from dust deposition in the nose, ears, eyes and upper respiratory tract or mechanical abrasion than from effects on the respiratory system or other system in the body. These types of dust may also cause eye problems, due to their concentration and suspension in air. In Australia, dusts not otherwise classified have a TWA of 10 mg.m$^{-3}$, measured as the inspirable fraction.

However, to apply such a TWA the dust must not contain a proportion of other toxic contaminants that do have their own national exposure standard. For instance, if a dust contains asbestos or more than 1 per cent of crystalline silica, the exposure standards for these materials are applied. These are known as mixed dusts. In such a case, it is always worthwhile to collect a sample of dust prior to occupational hygiene sampling and analyse for specific analytes. This will provide an overview of the most likely contaminants that workers will be exposed to. The next step is to make a decision on the appropriate monitoring technique. For instance, houses built in the 1960s frequently were roofed with asbestos-
cement (AC) sheeting. If the roofing were to be cleaned and exposure to contaminants was to be determined, sampling for asbestos rather than cement would be conducted.

**FIBRES**

Fibres refer to particles that have a thread-like appearance, with a specific length to width ratio. Some examples of fibres are asbestos, fibreglass, rock-wool and ceramic fibres. The typical industries where exposure to fibres is likely include:

- demolishing and refurbishing of old buildings that have asbestos-containing insulation
- lagging on ships
- fitting of vehicle brakes
- manufacturing of boats and surfboards.

Exposure to fibres such as asbestos has a notorious history of causing severe ill health and disease. Indeed, it is believed that the epidemic of mesothelioma (an extremely rare cancer of the pleura of the lung) of asbestos miners and their families in Wittenoom in Western Australia reached its peak some 30 to 40 years after exposure to crocidolite.

Solid particles (dusts and fibres) can be described as either isotropic or anisotropic. Isotropism refers to whether the substance has a crystalline or a non-crystalline structure. For instance, glass wool and mineral wool are both isotropic. Asbestos, wood, polyester and cotton fibres are fibrous forms of anisotropic substances. Non-fibrous forms of anisotropic dusts include gypsum, quartz, vermiculite, talc, magnesite and calcite.

**Asbestos**

The term asbestos does not describe a specific mineral but is a generic term applied to fibrous silicate mineral. These silicates usually are found in a fibrous crystal form, which can separate into flexible fibres when crushed. Some examples of sources of exposure include:

- **asbestos mining**, particularly in South Africa and Canada (the Australian blue asbestos mine, Wittenoom, has been closed)
- **thermal insulation lagging of pipes** in process plants, ships and furnaces
- **construction materials** such as millboard and AC sheeting for roofs and backing around heater banks
- **fire-retardant** in high-rise buildings, mostly between floors
- **compressed asbestos** in brake linings and gaskets
- **acoustic insulation** in false ceilings of schools, hospitals and public areas.

**Types of asbestos**

Asbestos is categorised into two main areas according to the physical structure of the fibres: serpentine and amphibole.

The serpentine group has fibres that have a curved or wavy appearance. Due to this structure, they are more likely to break into long but relatively thin particles. Chrysotile or white asbestos is a form of serpentine asbestos. It has been utilised for more than 90 per cent of all asbestos use today. It has the chemical composition $\text{Mg}_6(\text{OH})_8\text{Si}_4\text{O}_{10}$. This can be explained as magnesium oxide–hydroxide octahedra bonded with a layer of silicon dioxide tetrahedra. Chrysotile is thought to be formed when hot mineralised water entered cracks between magnesium silicate rocks, causing the dissolution of some of the rock. Crystals formed crosswise in the rock as the water cooled.

Amphibole asbestos has relatively straight and long fibres. They also have a tendency to cleave longitudinally, meaning their length to width ratio is quite high.
They have a chemical formula of \((\text{CaNaMn})_2(\text{MgFrTiAlMn})_5\text{SiAl}_8\text{O}_{22}(\text{OHF})_2\) and are believed to have formed from altered sedimentary rocks. Some examples of the amphiboles are:

- amosite (brown asbestos), also known as fibrous cummingtonite or grunerite
- crocidolite (blue asbestos), also known as fibrous riebeckite
- tremolite
- actinolite
- anthophyllite.

The nature of the application of asbestos can be classified into the following five categories:

- **AC products** (e.g. roofs)
- **asbestos-filled products** (e.g. mastics, glues)
- **asbestos insulation products** (e.g. fire retardant)
- **asbestos textiles** (e.g. asbestos)
- **other** (e.g. asbestos filters, asbestos millboard).

**History of asbestos**

We have known about the incredible insulating properties of asbestos for centuries. The original use of asbestos has been traced to Finland and Scandinavia during the Stone Age, some 4500 years ago. Anthophyllite was used to make pottery. However, although the ancients had mastered this technology, it was not until the industrial revolution that asbestos really became an industrial material. Since this time, cases of asbestos-related lung disease have been documented. Around 1899, a 33-year-old British asbestos spinner approached a chest specialist about attacks of ‘bronchitis’. He was the last survivor of ten workers with whom he had first started working. After his death in April 1900, a post-mortem showed significant lung scarring, caused by exposure to asbestos dust.

In Britain, the hazardous nature of asbestos became more widely recognised around the 1930s. The Merewether and Price Report confirmed that, indeed, there was a real epidemic of asbestos disease among British asbestos workers (Dalton 1979). As a direct result, government regulations with the main aim to reduce dust exposure were drawn up and became effective in 1933.

**Health effects from exposure to asbestos**

Inhalation of asbestos can lead to several distinct effects. These are:

- **asbestosis**
- **benign pleural disease**
- **lung cancer**
- **mesothelioma**.

The most common disease is asbestosis or fibrosis of the lung (Selikoff & Lee 1978). Asbestosis usually shows up in the lower part of the lung. It is characterised by a honeycombed appearance of the lung during a radiographic scan. This is believed to be caused by the inhaled asbestos fibres damaging the cell membrane of macrophages, allowing the release of enzymes and other components. The main factor that affects the likelihood of development of asbestos-related disease is cumulative exposure. It is believed that fibres whose length exceeds 10–20 µm are fibrogenic while the shorter fibres are not. The symptoms of asbestosis include a consistent reduction in the vital capacity of the lung, where any other form of chronic chest disease or airway obstruction is not causing the reduction.

Another ailment from exposure to asbestos is benign pleural disease. The pleura is the lining of the lung. The symptoms show as a calcification of regions of the pleura called pleural plaques. Another disease, bronchial carcinoma, is the medical term for lung cancer. Exposure to asbestos and cigarette smoking
has an additive effect on the risk of lung cancer. There is an increased risk of lung cancer in asbestos workers who develop asbestosis.

The final condition that is associated with asbestos exposure is mesothelioma or cancer of the lung lining (pleura). It has been closely linked with exposure to crocidolite. The issue with mesothelioma is that it is normally an exceptionally rare disease in the community. Epidemiological studies have shown that a typical dose–response curve is followed with mesothelioma and other asbestos diseases; however, with mesothelioma, the disease can result from even low-level exposure.

In Australia, the most widely publicised disaster with regard to mesothelioma involved mine workers and their families at the Wittenoom crocidolite mine in Western Australia. However, many other asbestos industries in Australia have produced higher numbers of mesothelioma cases. Mesothelioma is an extremely painful and aggressive cancer. The tumour is seen in an X-ray as a dense white growth that can spread to the whole lung and cause its collapse. Due to its aggressive nature, it is usually fatal within a few months.

**Sampling for asbestos**

Asbestos usage in Australian industries is now minimal and most asbestos investigation will involve ‘in situ’ products in workplaces such as ships, power stations and buildings. When assessing the risk of asbestos exposure, it is important to consider a number of factors before jumping to conclusions about its hazardous nature. Since asbestos is a particularly emotive issue, when dealing with asbestos (or suspected asbestos), it is important to correctly identify its presence and type. The first questions to ask are:

- **Has the sample been confirmed as asbestos?** What is its type and relative composition?

  - **What is the condition of the asbestos?** Is it friable (easily crumbled) or tightly bound in a matrix?
  - **Where is it sited?** Is it in a high-traffic area or in an isolated location where exposure is rare?
  - **Is it in a direct airstream?**
  - **How accessible is it?**
  - **What control procedures are currently in place?**

It is always wise to collect a sample of the suspected asbestos to enable correct identification by an accredited laboratory. Usually a sample of 100–250 g is sufficient to enable its identification. If the suspected asbestos is located in a number of areas or layers, each of these should be collected. For instance, checking the surface layer of lagging may indicate the sample is asbestos-free, when asbestos is in a lower layer. The sample should be sealed in an appropriate container or plastic bag and clearly labelled with its location, time and date that the sample was collected and the name of the person collecting the sample.

**Identifying asbestos**

The laboratory techniques for identifying asbestos include:

- **polarising light microscopy (PLM) with dispersion staining (DS) techniques**
- **analytical electron microscopy**
- **infrared (IR) spectroscopy**
- **X-ray diffraction (XRD).**

The most thorough technique uses a combined approach of PLM and DS microscopy. PLM is the most common method used due to its ease of application and relatively low cost. However, it may not confidently distinguish between forms of asbestos. This is where combination with DS becomes a useful tool. IR spectroscopy and XRD do not differentiate
between the fibrous and non-fibrous forms of the material.

With the PLM–DS technique, the optical characteristics of the fibres are considered. The process can be divided into the following steps:

- **Make an initial examination** using a low-power setting on the polarising light microscope.
- **Treat the sample** to distinguish between fibres and other matrix components such as cement.
- **Examine the fibre fraction** using a low-power stereoscopic microscope and mount in refractive liquid on a glass slide with coverslip.
- **Use the polarising light microscope with a rotating stage and first-order red plate** to identify the existence of asbestos.
- **Examine the sample** using refractive index immersion liquids of known dispersion characteristics and identify the exact asbestos type.

The first step is to review the morphology of the fibres using a low to moderate magnification. This will involve investigating the size and shape of the fibres with a magnification of between X5 and X10. The aim is to identify whether the sample contains more than one layer. If it does, each layer must be divided and treated separately.

After the substance is divided into distinctive sections, it may be necessary to treat the samples with water and cold dilute hydrochloric acid to free the fibres from their matrix. This is particularly important for substances such as AC-sheeting or millboard where the asbestos is bound. It is important to completely dry the sample at this stage. Next, the sample is gently teased apart, using fine-point tweezers. Since the sample may actually consist of several types of fibres, it is important that each of these is looked at separately. The fibres are then mounted on a glass slide and covered with a cover slip. As the identity of the sample is unknown at this stage, the sample should be treated with the utmost care, preferably in a glove box or exhaust ventilation system.

A polarising microscope with crossed polars and a first-order red plate is used to analyse the sample. As the sample is rotated over the plate, the fibres' colours will change. For instance, amosite and chrysotile have a wavelength change from blue to yellow when rotated clockwise. This is called length slow. Crocidolite changes from yellow to blue. This is called length fast.

Since the first-order red plate only differentiates between length-slow and length-fast fibres (i.e. amosite/chrysotile or crocidolite), the DS technique is used for further analysis. The microscope is adjusted so that the analyser and first-order red plate is removed and a central step objective is used. A liquid with a specific refractive index is placed on the sample. Using east–west polarisation, the colours will change as the sample is rotated.

The only disadvantage of this method occurs where the asbestos fibres are contained in a fibrous inorganic matrix or if the fibres are short. The dispersion effects of the matrix cause a ‘milky way’ effect and overwhelm that of the fibres.

**Monitoring for asbestos**

Monitoring for asbestos should be conducted according to the NOHSC's Asbestos Code of Practice and Guidance Notes or the Membrane Filter Method for Estimating Airborne Asbestos Dust. These define monitoring as either occupational or para-occupational. Occupational sampling refers to the collection of samples in the breathing zone, which are compared with the NES to assess workers’ exposure. Para-occupational or area sampling is frequently used to assess the effectiveness of
controls. It places samplers both within the work area and outside the operations (for instance, during an asbestos stripping operation) to identify the existence of asbestos fibres.

For occupational sampling, the equipment that is required includes:

- **a sampling pump**
- **filter holder** — a cowled asbestos sampling head (Figure 4.9) is used to protect the filter from accidental contamination
- **a 25-mm gridded filter** (preferably mixed esters of cellulose or cellulose nitrate) with a nominal pore size of 0.8 µm; although it is acceptable to use 13-mm filters provided that the flow rates and sample volumes are appropriately adjusted
- **flow calibration device**
- **time measuring device**
- **connective tubing**
- **belt for placement of the pump.**

The major difference between asbestos sampling and inspirable or respirable dust sampling lies in the collection of the dust size. For asbestos sampling, it is not the mass of dust that is determined but the number of fibres that meet a specific size criterion during counting. This is why a size-selective sampling device is not required.

The open-face asbestos cowl can be made of either metal or conductive coating (not plastic) to ensure the filter is not accidentally contaminated or electrostatic charge does not cause repulsion of the fibres. Filter holders and cowls must be thoroughly cleaned using detergent and water before the sampling.

The sampler is prepared by placing a 25-mm filter onto a supportive pad before inserting into the sampling head. The protective cowl is then attached and a cover attached for transportation to prevent contamination. (Although it is vital to remember

![Asbestos sampling head and cover](image-url)
to remove the cover for sampling!) The sample or a number of sub-samples is then collected over the total shift, although the sampling period should never be less than four hours.

The actual sampling duration will be influenced by the minimum and maximum loading of fibres on the filter. The determined flow rate will also need to be taken into consideration when assessing the monitoring duration. A volume of 100 L (±20 per cent, i.e. 80 – 120 L) will need to be collected. The preferred range of flow rate is 0.4 – 2 L.min⁻¹.

The sampling train is calibrated both before and after sampling. If the difference in flow rate is more than 10 per cent greater than the initial flow rate, the sample must be rejected. Acceptable minimum and maximum loadings of fibres on the filter are shown in the NOHSC Asbestos Code of Practice.

With para-occupational sampling, the equipment is identical to that of occupational sampling, although it is accepted that in certain cases it may be necessary to collect single samples of short duration. However, since the aim of para-occupational sampling is to identify background or low levels of asbestos, it is necessary to increase the volume of air sampled. The following list shows the sampling parameters for performing para-occupational sampling of asbestos:

- **flow rate of 1 to 8 L.min⁻¹**
- **volume of 500 L (±20 per cent, i.e. 400–600 L)**
- **where it is suspected that there are very low airborne fibre concentrations**, the sample volume can be increased to a maximum of 1000 L.

For both types of sampling it is necessary to keep blanks for each batch of filters or for every 25 filters in the batch. The blank is subjected to the same treatment of sampling and handling but a sample is not collected. It is then analysed with the sampled filters.

**Asbestos counting**

Once the samples of fibres have been collected on the gridded filter paper, they must be prepared for counting.

After sampling has finished, the cap of the sampling head is firmly attached and the capped cowls packed securely for transportation. It is important that they are not exposed to vibration or mishandled as this may dislodge the fibres from the filter. Once back at the laboratory, the filter is prepared for counting.

**Clearing the filter**

A 25-mm filter is cut cleanly in half and mounted on a glass slide. If the filter has a diameter of 13 mm, the entire filter must be mounted. The cut can be performed using a sharp blade such as a razor or curved-blade scalpel. It is important that the cut is made in one action so that the sample is not disturbed. Since the filter at this stage is opaque, it must be ‘cleared’ to allow the fibres to be counted through an optical microscope. Most laboratories use the ‘hot-block’ method, where a small amount of acetone is quickly vaporised and directed onto the filter.

The filter should be left to stabilise for at least five minutes after it has been cleared. It is then treated using glycerol triacetate (triacetin). This is performed by dropping 5–10 µL of triacetin onto a coverslip before lowering the cleared slide onto it. This process assists in making the sample stable so that it will not disintegrate or be subject to particle migration. If the slide is to be kept indefinitely, nail polish or a similar lacquer should be painted around the edge of the coverslip.

**Counting**

The procedure for counting asbestos fibres should only be conducted in a properly accredited laboratory, such as one that has been NATA accredited and where the counters are appropriately certified. The microscope should have:
• a light source
• a chromatic phase-contrast
  condenser
• stage
• specific objectives
• binocular eyepieces with a total
  magnification between X400 and
  X650
• a Walton-Beckett circular eyepiece
  graticule.

Once the prepared filter has been placed on
the stage, the entire filter area should be
scanned with a total magnification of X100 to
X150. At least half of the mounted filter area
must be countable otherwise the filter is
rejected. Some factors that will affect its
countability include significant differences in
loading or major aggregation of fibres or
dusts. The microscope objective is then
changed to X40-phase contrast, ensuring that
the rings remain concentric. It is also necessary
to focus on both the surface above and
below it.

With asbestos counting, the most
important point to remember is the counting
criteria or the fibre length and diameter that
are critical. A respirable fibre is defined by the
NOHSC as a fibre that:

• has a maximum width less than 3 µm
• has a length greater than 5 µm
• has a length-to-width ratio greater
  than 3:1
• does not appear to touch any
  particle with a maximum dimension
  greater than 3 µm.

A countable fibre also must be entirely inside
the graticule area. The graticule is a circular
field that is contained in the eyepiece of the
microscope. It is within the graticule that the
asbestos fibres are counted. If one end is
outside the area, it is counted as half a fibre. If
both ends are outside the area, it is not
counted.

The counting criteria also specifies that:

• an agglomerate of fibres is known as
  a split fibre, if it appears to be solid
  and undivided in some areas and
  divided into separate strands in other
  areas
• fibres that touch or cross
  one another are known as
  a bundle
• a split fibre is a countable fibre if it
  meets the definition of a countable
  fibre when measured across the un-
  split section
• a bundle of fibres can be counted
  individually where the distinction is
  clear, otherwise the entire bundle is a
  countable fibre if it meets the
  definition of a countable fibre as a
  whole
• where more than one-eighth of the
  graticule area is covered by an
  agglomerate, it is rejected and
  another counted
• a total fibre count of 100 must
  be obtained; however, a minimum
  of twenty fields must be counted
even if more than 100 fibres are
  counted, and if ten fields are
  counted without reaching
  100 fibres, the counting ceases
  and records of the counting are
  recorded.

Calculating asbestos
fibre exposure and
reporting results

Once the fibres on the filter have been counted
and the results recorded, the actual
concentration of fibres can be determined. For
a single sample, Equation 4.7 shows the
equation that is used.
Equation 4.7

\[ C = \frac{A}{a} \times \frac{N}{n} \times r^{-1} \times t^{-1} \]

Where:
- \( C \) = concentration (f.mL\(^{-1}\))
- \( A \) = effective filter area (mm\(^2\))
- \( N \) = total number of fibres counted
- \( a \) = eyepiece graticule area (mm\(^2\))
- \( n \) = number of graticule areas observed
- \( r \) = flow rate of air through filter (mL.min\(^{-1}\))
- \( t \) = single sample duration (minutes)

The blank filters that have been saved must be analysed in the same way as the sample filters. However, if the blank count shows greater than 3 fibres/10 graticule areas, the whole monitoring technique should be re-evaluated for sources of contamination. If the blank count exceeds 3 fibres/100 graticule areas and exceeds 10 per cent of the actual sample fibre count/100 graticule areas, the samples relating to the blank should be rejected.

Exposure standards for asbestos

The exposure standards for forms of asbestos are specified in the NOHSC’s NES. They are expressed as time-weighted averages (TWA), due to the long-term effects of exposure (Table 4.2).

<table>
<thead>
<tr>
<th>Type of asbestos</th>
<th>TWA (f.mL(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crocidolite (blue asbestos)</td>
<td>0.1</td>
</tr>
<tr>
<td>Amosite (brown asbestos)</td>
<td>0.1</td>
</tr>
<tr>
<td>Chrysotile (white asbestos)</td>
<td>1.0</td>
</tr>
<tr>
<td>Other forms</td>
<td>0.1</td>
</tr>
<tr>
<td>Any mixture of these, or where the composition is unknown</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Synthetic mineral fibres

Since the development of rock- and slag-wools in the late 1800s, fibreglass in the 1930s and refractory ceramic fibres (RCF) in the 1950s, workers have been exposed to various airborne levels of the dusts and fibres of these products. These are all examples of synthetic mineral fibres (SMF), man-made mineral fibres (MMMF) or man-made vitreous fibres (MMVF). In recent times, there has been a heightened awareness of the potential health risks of materials that produce dusts or fibres that may be inhaled.

There are four groups of SMF:

- glass filament
- ceramic fibres
- insulation wools
- special purpose fibres.

Of particular interest for their potential health effects are the insulation wools and ceramic fibres.

Fibrous glass

The two basic forms of fibrous glass are: wool-type glass fibres and textile glass fibres.

Wool-type glass fibres are manufactured by spinning or blowing molten glass and have good insulation properties to around 450°C. They also are useful in insulating workplaces and offices from noise. Fibres average 3–8 µm in diameter.

Textile glass fibres are drawn or extruded in a continuous process from holes in a bushing placed in the base of a platinum container. They are generally larger and more uniform than wool-type glass fibres. Their diameters are 6–15 µm. Typical application includes reinforcement of other materials such as plastic items.
**Mineral wool**

This category is also divided into two basic types: slag-wool and rock-wool.

Slag-wool is made from the by-product of metal smelting which is then drawn or blown into a fibre. The resultant mineral wools are predominantly used in insulation for industry at temperatures up to 650°C.

As the name suggests, rock-wool is produced from igneous rock. The rock contains high levels of calcium and magnesium.

**Refractory ceramic fibres**

These can be kaolin-clay-based products, blends of alumina, silica and refractory metal oxide or high-purity products such as alumina and silica blends. Due to their chemical compositions, their most common application is as high-temperature insulators (1050°C–1425°C). The typical range for actual fibre diameters is 0.2–0.5 µm.

**Health effects from exposure to synthetic mineral fibres**

SMF have largely replaced the use of asbestos due to their similar thermal and acoustic insulating properties. Existing human studies and animal experiments indicate that all types of SMF present much less of a risk to workers, compared with asbestos. Notwithstanding, consideration still needs to be given to the fibre dimensions, characteristics of fragmentation, degree of exposure and chemical composition. All of these factors can impinge on the potential risk of ill health or disease.

The IARC classified SMF in 1987. It concluded:

... that glasswool, rockwool, slagwool and ceramic fibre may possibly be carcinogenic to humans (group 2B). Glass reinforcing filament is not classifiable (Group 3) based on insufficient evidence in both human and animal studies. The IARC classifications are based on a review of evidence that the disease could occur. They do not necessarily reflect the level of risk that is likely to exist in the workplace (NOHSC 1989, p. 9).

More recently, on the basis of high dose animal studies, RCF have been thought to lead to significant adverse health effects (Bunn et al. 1993). Epidemiological studies conducted on the production workforce do not indicate significant health effects. Fibreglass and rockwool have been shown to cause adverse health effects in some animal studies. However, epidemiological studies do not indicate significant risk. This is thought to be due to their small diameters (0.2–0.8 µm), which is similar to that of asbestos. Exposure to glass filaments such as fibreglass has not been proven to be linked to disease. Again, this is due to their large diameters. Notwithstanding, fibreglass is extremely irritating to the skin and can cause a form of dermatitis due to the fibres becoming imbedded in the skin. A national standard on the safe use of SMF was released by the NOHSC in 1990 and this can be used to minimise risk.

**Monitoring for synthetic mineral fibres**

Sampling and counting for SMF is very similar to the method used for asbestos and is comprehensively described in the NOHSC document, ‘Technical Report on Synthetic Mineral Fibres and Guidance Note on the Membrane Filter Method for the Estimation of
Airborne Synthetic Mineral Fibres’. The method also uses a cowled sampling head with a gridded filter, preferably mixed cellulose esters. The air sample is drawn through the filter using a sampling pump connected by flexible tubing that has been calibrated at a known flow rate. Following sampling, the filter is mounted and the number of countable fibres is determined using a microscope. For specific details about SMF sampling technique, refer to the previous section on asbestos monitoring.

**Exposure standards for synthetic mineral fibres**

The exposure standards for SMF are expressed as the TWA. For respirable fibres, this is $0.5 \text{ f.mL}^{-1}$. For non-respirable fibres, a secondary exposure standard has been proposed. This aims to minimise the irritant effects from exposure to the upper respiratory tract and is expressed as $2 \text{ mg.m}^{-3}$.

### SUMMARY

Dusts and particulate are examples of occupational hygiene hazards that may present a risk to workers’ health. Dusts are categorised according to their aerodynamic equivalent diameter and are broadly known as either respirable or inspirable (inhalable) dusts. Some examples of occupationally related dusts include crystalline silica, wood dusts, organic dusts and coal dusts. Fibres have solid, thread-like filaments that have a defined length-to-width ratio. Asbestos and synthetic mineral fibres are examples of these.

In Australia, respirable dust is sampled according to AS2985. Inhalable dust is monitored according to AS3640. Direct-reading sampling devices are also available to monitor for airborne dusts and fibres.

### BIBLIOGRAPHY AND FURTHER READING

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Chapter 5

Metals

In recent times, Australia has been referred to as a lucky country. While there are many interpretations of the true meaning of luck, perhaps one aspect can be attributed to Australia’s natural resources, including metal ore deposits. Metals have a broad range of application in industry and indeed the community. Where would we be without motor vehicles, electrical devices and jewellery?

Unfortunately, many metals can cause adverse health effects to workers and pollute the environment. The term 'heavy metal pollution' originally referred to pollution by mercury, lead and cadmium but has since extended to cover other toxic metals such as silver, arsenic, chromium, copper, nickel and zinc. Other toxic metals include manganese, antimony, beryllium, boron, cobalt and thallium.

This chapter provides a discussion of occupationally significant metals, including the following information:

- their sources in industry
- route of entry and toxicological effects
- national exposure standards
- techniques for conducting occupational hygiene monitoring and biological monitoring.

THE TOXICITY OF METALS

Metals affect systems and organs within the human body in different ways. To understand the mechanism of effect of exposure to metals, we must begin with a description of the chemical structure and properties of metals and the reasons why they are differentiated from other occupational hygiene hazards. Metallic elements and metallic compounds (alloys) are strong, lustrous and malleable. They are also able to conduct electricity. This makes them extremely versatile in a number of applications, such as:

- copper drawn out into threads for use in electrical wire
- aluminium used as a reflector of heat
- steel pressed into the shape of motor vehicle panels
- platinum and gold for jewellery.

In the periodic table, most elements are metals. The metallic elements are found in groups I to VI and also in the transition block. You can find the periodic table at the front of this book. Most of the metallic elements have very few electrons in their outer shell. This means that the bonding of metals occurs as the positive ions from each atom repel one another but are attracted to the negative ions (electrons).
This association between positive and negative ions forces the atoms to bond together strongly. It also helps explain why metals conduct electricity so well. Since the electrons are not bound to any particular atoms, they are able to move in an electric field (the flow of electricity is essentially the flow of electrons).

In our bodies, metals are needed for normal functioning and homeostasis. However, the levels of essential metals must be kept within a concentration window. The concentration window refers to a concentration range below which the body suffers a deficiency and above which the metal is toxic. With typical absorption, essential metals are taken up from the gut. Here, they bind with a carrier protein and transport (or store) protein, and are moved throughout the body. But non-essential metals also use this path, taking advantage of the same mechanism. The degree of uptake of non-essential metals is therefore influenced by the concentration of other metals in the gut.

Essential metals have several functions in the body. Mostly, they are bound to enzymes (as metalloenzymes) in order for the enzyme to become activated. Their use includes assisting in the carriage of oxygen (iron in haemoglobin), as cellular messengers (calcium acts as a trigger mechanism for the nerves' postsynaptic transmission and muscle contraction), in the structural components of proteins and as nucleophiles. Common metals found in enzymes include sodium, potassium, calcium, magnesium, manganese, zinc, iron, cobalt, nickel, molybdenum and tungsten.

Another important part of metal toxicology is metals' ability to interact with other metals. This can result in a synergistic or antagonistic relationship.

For instance, exposure to cadmium can cause the displacement of zinc in some metalloenzymes. Lead can cause the displacement of calcium, which leads to the storage of lead in bone and inhibition of postsynaptic transmission.

**NATURE OF CONTAMINANT AND ROUTES OF ENTRY**

Metals and their compounds can exist in a number of forms (dust, fume, mist, vapour or gas). In an industrial setting, however, most occupational exposure occurs from particulate or aerosols. This occurs because most metals and their salts are solids. The exception is mercury and some metal hydrides such as arsine and stibine, which exist in the gaseous state or have a high enough vapour pressure at room temperature to exist as a vapour. Some examples of exposure to metals include:

- **lead oxide (PbO) fume** when removing impurities from gold
- **mercury (Hg) vapour**, where a manometer has blown/broken
- **zinc oxide (ZnO) fume** from the production of metallic zinc after roasting of zinc sulphide ores, which are then reduced using carbon monoxide
- **tungsten carbide and cobalt dust** from machine grinding of hard metal tools.

In some cases, elements are not strictly metallic. These substances are known as metalloids. The metalloids include boron, silicon, germanium, arsenic, antimony, tellurium and polonium. Metalloids have similar properties to both metals and nonmetals. For instance, they conduct electricity poorly under certain conditions and are called semiconductors. Semiconductors find use in electronics and computers because of this characteristic. This chapter discusses the hazardous nature of some metalloids along with metals.

Metals may show their effects through acute or chronic exposure. Acute effects result from the inhalation of air or ingestion of
liquids containing metals in very high concentrations. Some metals such as mercury and thallium may be absorbed through the skin. Inhalation of high concentrations of metals is irritating and may cause severe damage to the respiratory tract. Many metals are also sensitisers. Exposure to nickel, for instance, may lead to a rash called nickel itch. Other metals (e.g. chromium) can cause corrosion of the skin and mucous membranes.

Chronic exposure to metals has also been well documented, for instance:

- **lead exposure** from operations reclaiming lead-acid accumulator batteries
- **felting involved the use of inorganic mercury compounds**, which caused severe central nervous system symptoms including a pronounced tremor
- **manganese exposure** from welding hard metals, such as dragline buckets from coalmines
- **inorganic arsenic**, an impurity of lead and copper ores, is given off during the smelting process.

Since most exposure to metals occurs through inhalation of particulate (dust or metal), most workplace monitoring requires sampling of dusts. However, where the metal becomes airborne as an aerosol (such as in an electroplating process where chromium and nickel are the metals), these aerosols are monitored in a similar fashion to particulate clouds containing metals.

**SPECIFIC METALS AND THEIR RISKS**

Having said that many metals are essential to the normal functioning of the human body, there are still some twenty or more metals that are not required for homeostasis. Even where the body does require essential metals, doses beyond the optimal concentration window may also be of concern. Exposure to these metals has the potential to damage the body and places workers at risk of ill health and disease. The metals, metal hydrides and metalloids that are considered in this chapter include:

- aluminium (Al)
- antimony (Sb) and stibine (SbH₃)
- arsenic (As) and arsine (AsH₃)
- beryllium (Be)
- boron (B)
- cadmium (Cd)
- chromium (Cr)
- cobalt (Co)
- copper (Cu)
- gold (Au)
- lead (Pb)
- manganese (Mn)
- mercury (Hg)
- nickel (Ni)
- osmium (Os)
- platinum (Pt)
- selenium (Se)
- silver (Ag)
- thallium (Tb)
- tin (Sn)
- titanium (Ti)
- tungsten (W)
- vanadium (Vn)
- zinc (Zn).

**Aluminium**

Workers can be exposed to aluminium (Al) in its metallic form as dust or fume, aluminium oxide (alumina or Al₂O₃), alkyl products (–NOC⁺), pyro-powders or as the soluble aluminium salts. Aluminium is used in the manufacture of:

- **domestic cookware** (pots, pans, trays)
• food wrappings (aluminium foil)
• building materials (roofing, cladding, window frames)
• electrical wire (instead of copper)
• alloys for the aircraft and motor vehicle industry.

Aluminium is found naturally, mostly as a component of feldspar, mica and bauxite. Bauxite was first discovered in the French district of Les Baux in 1821. Several processes for aluminium production were used until, in 1886, American Charles Hall and Frenchman Paul Heroult both found a method of producing aluminium by electrolysis. This was called the Hall–Heroult process and is still used today.

However, the most common refining process for extracting alumina from bauxite was developed by Karl Bayer in 1888 and is known as the Bayer process. In Australia, bauxite is found in the Darling Range and Kimberley Region in Western Australia, and in the Pinjarra area. In Queensland, it is mined from Weipa.

When ignited, finely divided aluminium burns with a hot flame to form aluminium oxide (Al₂O₃). It is also readily oxidised by chlorine to produce aluminium chloride (AlCl₃). Aluminium chloride sublimes around 180°C.

In recent times, aluminium poisoning has been associated with central nervous system effects that reflect the symptoms of Parkinsonism. The effects may include a loss of memory, tremor and jerkiness of movement.

It has also been suggested that aluminium exposure may be a factor for patients with senile and pre-senile dementia (Alzheimer type) and in Parkinsonism dementia. It is believed that aluminium is a major toxic causation of renal dialysis encephalopathy, which can lead to problems with speech, dementia and convulsions.

In Australia, the NOHSC has specified occupational exposure standards (TWA) for aluminium and its compounds as:

- aluminium oxide (Al₂O₃ or alumina) and aluminium metal dust — 10 mg.m⁻³
- aluminium welding fumes (as Al) — 5 mg.m⁻³
- aluminium alkyls (as Al) and soluble salts (as Al) — 2 mg.m⁻³
- aluminium pyro-powders (as Al) — 5 mg.m⁻³.

Sampling and analysis of aluminium and compounds will depend upon its state of matter and the aerodynamic equivalent diameter of the dust cloud. For instance, aluminium oxide is sampled for the inspirable fraction according to AS3640, using an IOM or UKAEA size-selective sampling head that is calibrated in-line at 2 L.min⁻¹. If the respirable fraction of aluminium is sought, sampling should be conducted by following AS2985. Chapter 4 discusses the principles of inspirable and respirable dust sampling.

To analyse the filter, inductively coupled plasma (ICP) or atomic absorption spectroscopy (AAS) could be used. ICP analysis relies on the ionisation of atoms in an aqueous solution, which transforms it into an aerosol. The light that is emitted from the atoms is then converted to an electrical signal to compare with pre-viously measured intensities of known elements. Since each element will have a specific wavelength, the individual element can be identified. ICP is especially useful to identify many metals that may be present in one sample. It also has a high sensitivity, with low detection limits.

Often, ICP is coupled with other analytical instruments, such as atomic emission spectroscopy (AES) and mass spectroscopy (MS). When combining ICP with MS, greater discrimination between the various isotopes of the element is possible. ICP–AES has been widely used since the 1970s for simultaneous multi-element analysis. This combination of methods allows for excellent sensitivity and a wide working range for many elements.
AAS relies on measuring the light wavelengths that are absorbed by each element when they have been thermally excited. The sample is aspirated into a specific flame or vaporised with an electrical furnace. A light beam of specific characteristic wavelengths is then directed through the vapour and the amount of light absorbed is measured.

**Antimony and stibine**

Antimony (Sb) is a silvery-white metalloid. It is quite brittle and breaks easily. Due to this characteristic, antimony is mostly alloyed with other metals, such as zinc and lead, to form solids such as:

- **batteries**
- **solder**
- **sheet metal and pipe metal**
- **ammunition**
- **pewter.**

High-grade antimony is used to make semiconductors. Other compounds such as aluminium antimonide, gallium antimonide and indium antimonide are used for thermoelectric devices such as infrared detectors and diodes. Antimony trioxide is used as a fire retardant in plastics, textiles, rubber, glues, pigments and paper. Antimony trioxide is classed as a Category 2 carcinogen.

Other antimony compounds include antimony pentasulphide, antimony chloride, antimony pentoxide, antimony potassium tartrate, antimony trichloride, antimony trisulphide and stibine (SbH₃, antimony hydride, which is formed when antimony is exposed to nascent hydrogen). The occupational health hazards of stibine are discussed in Chapter 6.

In normal conditions, antimony metal is quite stable and a poor conductor of heat and electricity. It is incompatible with strong oxidising substances, acids and halogenated acids. If exposure to antimony occurs, it is likely to happen through inhalation or the skin. The symptoms of exposure include:

- **irritation of the nose, throat, skin and mouth**
- **cough**
- **dizziness and headache**
- **nausea and vomiting**
- **stomach cramps, insomnia, anorexia and inability to smell properly.**

The body may show clinical effects such as:

- **pneumoconiosis**
- **increased blood pressure**
- **abdominal distress and ulcers**
- **dermatitis.**

Exposure to antimony trichloride can result in cardiac abnormalities. Antimony is excreted in the urine; therefore, workers with kidney problems may be at higher risk.

The occupational exposure standards (TWA) for antimony and antimony compounds are:

- **antimony and antimony compounds (as Sb)** — 0.5 mg.m⁻³
- **handling and using antimony trioxide (as Sb)** — 0.5 mg.m⁻³
- **production of antimony trioxide (as Sb)** — as low as practicable (due to its carcinogenic properties).

Antimony particulate can be monitored as the inspirable fraction, according to AS3640. Once sampling is complete, the filters can be analysed with AAS or ICP using a similar technique to that used to analyse aluminium.

**Arsenic and arsine**

Arsenic (As) has been seen as the poison of choice in many thriller novels. The major occupational health risk associated with
arsenic occurs through the inhalation of dust. Arsenic is actually a metalloid, which is often alloyed with lead in the production of cable sheaths or battery grids. Solid arsenic comes in two forms or allotropes: grey, metallic arsenic and yellow, nonmetallic arsenic (As\textsubscript{4}).

Oxides and complex salts of arsenic are used in the production of weedkillers, insecticides, wood preservatives and fungicides. An example of inadvertent exposure to arsenic compounds occurs when logs treated with chromated copper arsenate (CCA), for outdoor and garden use, are burned. This causes the arsenic to be converted to the extremely toxic arsenic trioxide. Another strange source of arsenic has been found in groundwater run-off from cemeteries. In the late nineteenth century, embalming fluid containing arsenic was used to preserve bodies. Once buried, the arsenic contaminated the groundwater.

Inorganic arsenic compounds are absorbed through inhalation, ingestion and through intact skin. They are stored in the tissue and tend to accumulate in the muscles and liver. Arsenic is excreted through the kidneys.

The effects of exposure are very much dependent upon the arsenic’s chemical form. While acute poisoning in the workplace is rare, arsenic has been implicated in suicides and homicides. The first symptoms of acute exposure are severe respiratory irritation with cough and chest pain. Chronic exposure to arsenic is seen as:

- irritation of the nasal mucosa (sometimes the nasal septa perforate from the corrosive effect)
- thickened and pigmented skin
- stomach pain and diarrhoea
- nausea and vomiting
- numbness of the soles and palms that develops into a painful condition called neuritis
- lung cancer and respiratory tract cancer.

The health effects of arsine gas (AsH\textsubscript{3}) are described in Chapter 6, and include headache, giddiness, abdominal pain and vomiting.

The NOHSC exposure standard for inorganic arsenic salts, metal and soluble salts is 0.05 mg.m\textsuperscript{–3} (TWA). It is 0.05 ppm or 0.16 mg.m\textsuperscript{–3} for arsine. Air monitoring depends on the form of the arsenic. For instance, arsenic trioxide is collected on filters treated with sodium hydroxide. Arsenic particulate is collected as inspirable dust and arsine is collected in a liquid impinger. There are also direct-reading colorimetric tubes which are available for both arsenic trioxide vapour and arsine.

Biological monitoring through analysis of blood and urine of workers is another option to review recent exposure. Normally, unexposed workers have blood and urine levels below 0.7 µmol.L\textsuperscript{–1} and 0.07 µmol.L\textsuperscript{–1}, respectively. Since arsenic can bio-accumulate in waterways, seafood or fish should not be consumed for at least three days before biological testing for arsenic is conducted.

**Beryllium**

Beryllium (Be) is a grey metal that is used for fibre optics and cellular network communication systems. Beryllium is also used as an alloy for electrical parts and aerospace applications, window material for X-ray tubes, a moderator material for nuclear weapons and in high-performance aircraft brakes. It also forms many compounds, including:

- beryllium chloride — a white or colourless crystal
- beryllium fluoride — a colourless, non-crystalline mass
- beryllium hydroxide — crystalline solid or gelatinous
- beryllium oxide (BeO) — a white, amorphous powder or gel
- beryllium sulphate — colourless crystals.
The occupational health hazard associated with beryllium compounds arises from toxic vapours that can be emitted. For instance, beryllium chloride, beryllium fluoride, beryllium hydroxide, beryllium oxide and beryllium sulphate emit BeO. In addition, beryllium chloride emits toxic fumes of hydrochloric acid and other chlorinated compounds; beryllium fluoride emits hydrofluoric acid vapour and other fluorinated compounds; and beryllium sulphate emits oxides of sulphur (SOx).

The primary routes of entry for beryllium and its compounds are through inhalation and the skin. Those most at risk include:

- beryllium ore miners and alloy makers
- ceramic workers
- missile technicians and nuclear reactor workers
- electric and electronic equipment workers.

In Australia, beryllium and its compounds are classified as Category 2 carcinogens. The IARC has reported that beryllium may lead to human lung cancer. It can also cause chronic beryllium disease. The latency period of this disease may be up to twenty years. It is believed that chronic beryllium disease involves a reaction with the human body’s immune system, affecting the respiratory tract and resulting in weakness, fatigue and loss of weight.

If acute exposure to beryllium occurs, this may show as symptoms of swollen mucous membranes, ulceration, a nonproductive cough and chest pains. This disease is known as acute beryllium disease and is similar to pneumonia. In Australia the national occupational exposure standard (TWA) for beryllium and its compounds is 0.002 mg.m$^{-3}$. It should be sampled as the inspirable fraction, according to AS3640, and analysed using ICP.

Boron

Boron (B) is a metalloid which is quite rare. Research suggests that boron is an essential metal, helping maintain the body’s level of minerals and hormones that are required for healthy bones. In industry it has been used to manufacture pure and strong metals (by removing the oxygen and nitrogen dissolved in the metal or chemically bound to it). It also finds application in absorbing fast neutrons in nuclear reactors.

Boron compounds are commonly used. These include borax, boric oxide, boron tribromide and boron trifluoride. Borax (Na₂B₄O₇·10H₂O) is combined with other metals such as chromium, copper, manganese, cobalt and nickel to form colourful substances such as borosilicate glass, which is highly refractive and used to make lenses. It is also used for increasing the fire resistance of textiles and wood; softening water for clothes washing; as a fertiliser where soils may have low levels of boron, and as a flux in brazing.

When ignited, amorphous boron has a green colour and is used in pyrotechnic flares and as an igniter of rockets. Boron compounds are also used in the production of enamels for covering the steel panels of whitegoods. Boron trifluoride is a very toxic and colourless gas, which fumes in moist air. It is used mostly as a catalyst in chemical process industries. Boron tribromide is also a gas.

The most toxic boron compounds are the borohydrides — diborane, decaborane and pentaborane. These are unstable and flammable, usually with a sickly sweet odour. Exposure may cause irritation of the skin, headache, chills, dizziness and weakness.

In Australia the occupational exposure standards (TWA) for boron compounds are:

- tetra borates (anhydrous) sodium salts — 1 mg.m$^{-3}$
• tetra borates (decahydrate) sodium salts — 5 mg.m$^{-3}$
• tetra borates (pentahydrate) sodium salts — 1 mg.m$^{-3}$
• boron oxide — 10 mg.m$^{-3}$
• boron tribromide — 1 ppm (peak limitation)
• boron trifluoride — 1 ppm.

The dusts of boron compounds (e.g. boron oxide and tetraboron salts of boron) are monitored as inspirable dust. The filters can be analysed gravimetrically and then further analysed using ICP. The gases (boron tribromide and boron trifluoride) are sampled using a midget impinger with a fritted nozzle.

**Cadmium**

Cadmium (Cd) is a metal with a soft, silver-white colour. It is usually found in combination with other elements and used as a:

• pigment
• component of batteries (e.g. NiCad batteries)
• constitute of alloys for iron, steel and copper in the electroplating industry
• welding and brazing solder.

The salts of cadmium (e.g. cadmium sulphide) are used as a pigment in paints, inks and plastics. The main hazard arises from the inhalation of cadmium or cadmium oxide vapour or dust, especially from burning fossil fuels such as coal and oil. It is also a by-product of zinc, lead and copper smelters. Smoking is another important source of cadmium. Smokers have about twice as much cadmium in their bodies as do nonsmokers.

Acute exposure to cadmium shows its effects mostly in the lungs as pulmonary irritation. The kidney is also a target organ with the accumulation of cadmium causing the damage. Even a single acute exposure to high levels of cadmium can cause long-term damage to the lungs including reduction of lung function. Cadmium and its compounds are categorised as Category 2 carcinogens.

Chronic exposure affects the kidneys, with the disease proteinuria which causes the glomerular filtration rate to decrease while an increase in kidney stones can occur. Chronic inhalation can also lead to emphysema or affect the liver, bones and immune, blood and nervous systems.

It is also reported that cadmium is one of the metals that may contribute to a condition known as metal fume fever. With this condition, the worker may suffer headache, cough, chill and fever.

Biological monitoring of the blood or urine can be used to indicate cadmium exposure. The samples are then analysed using AAS. In severe cases, a biopsy can be taken to measure cadmium concentrations in the liver or kidneys. However, this method is expensive and invasive. If urine is analysed, the ACGIH recommends a BEI of 10 µg/L.

The occupational exposure standard for cadmium is 0.01 mg.m$^{-3}$ for oxides, fume or metal cadmium. It can be monitored by collecting the inspirable dust fraction according to AS3640 (Chapter 4). The collected filters are then analysed using ICP or AAS.

**Chromium**

Chromium (Cr) is an essential metal that the body needs to stabilise blood sugar levels and for the metabolism of cholesterol, fats and protein. It is naturally found in food such as brewer’s yeast, capsicum, cheese, potatoes, whole grains, mushrooms, shellfish and chicken. From an occupational health perspective, metallic chromium is not a high risk to workers (it is inert). Indeed, chromium is an odourless, hard, lustrous metal. However, its salts can be irritating and corrosive, due to their oxidative characteristics.

The main salts of chromium are:
• chromium (0) — the metal
• chromium (II) — chromous
• chromium (III) — chromic (occurs naturally)
• chromium (VI) — hexavalent.

Typical applications where chromium exposure might occur include:

• plating elements on metal and plastics to minimise corrosion
• nuclear and high-temperature research
• electroplating cleaning substances for the metal finishing industry
• dyes and pigments
• medicinal antiseptics
• leather treatments and tanning
• mordants in the textile industry
• fungicides and wood preservatives such as CCA in treated timbers
• industrial water treatment (e.g. cooling tower water)
• production of chromic acid and specialty chemicals.

The health effects of exposure to chromium and its compounds depend upon their valency, state of matter and water-solubility. For instance, some water-insoluble chromium (VI) compounds are Category 1 carcinogens due to their ability to cause cancer of the respiratory tract. Hexavalent chromium substances (e.g. chromates, dichromates and chromic acid) are corrosive, causing ulceration and dermatitis. Allergic dermatitis has been well reported in cement and metalworkers, painters and leather tanners (Baruthio 1992). In serious cases of exposure, chrome holes appear around the joints of the fingers, the fingernails and eyelids. Perforation of the nasal septum may also occur.

The most dangerous effect from ingested chromium is acute renal tubular necrosis. The trivalent chromium compounds, Cr (III), are considerably less toxic than the hexavalent compounds and are neither irritating nor corrosive.

The NOHSC has provided occupational exposure standards for chromium metal and chromium compounds. Expressed as the TWA, these are:

• chromium metal — 0.5 mg.m$^{-3}$
• chromium (II) and (III) compounds (as Cr) — 0.5 mg.m$^{-3}$
• certain water-insoluble chromium (VI) compounds (as Cr) — 0.05 mg.m$^{-3}$; these substances are also Category 1 carcinogens and sensitisers
• water-soluble chromium (VI) compounds (as Cr) — 0.05 mg.m$^{-3}$; these are also sensitisers.

Occupational hygiene sampling for chromium and chromium compounds is best conducted using inspirable dust sampling techniques, although care should be taken in the selection of the filter. Special PVC filters with low moisture pick-up that are designed to collect chromic acid, chromates and hexavalent chromium should be used. If unsuitable filters are used, the collected dust or fume sent for analysis may not be in the correct valence for analysis.

Health surveillance for workers in an inorganic chromium process should include collection of information about their occupational and medical history and a physical examination of the respiratory system and the skin.

**Cobalt**

In the workplace, exposure to cobalt (Co) is typically found as dust or fume. Cobalt is an odourless, silver metal or black solid, which is used as an alloy ingredient of steel, especially for jet engines. In the textile and ceramic industries, the salts of cobalt (cobalt blue and cobaltous blue) are used for colouring glass, ceramics and textiles. Some cobalt components
find applications as permanent magnets, in nuclear technology and in abrasives and tools.

Exposure to cobalt may cause symptoms such as coughing, pulmonary oedema and decreased functioning of the respiratory system. The dust may cause dermatitis, with a rash or burning feeling, and fibrosis of the lung. The fibrosis can be fatal. The major effect is respiratory hypersensitivity (resulting in asthma-like responses such as wheezing, chest pain and shortness of breath). It has also been reported that exposure to cobalt can damage the heart. Chronic exposure is believed to damage the thyroid and liver. Some isotopes of cobalt are radioactive (e.g. $^{60}$Co, which is a beta and gamma emitter) and care should be taken to control exposure in these cases. Chapter 10 describes the effects of exposure to ionising radiation.

In Australia the TWA for cobalt metal and dust (as Co) is 0.05 mg.m$^{-3}$. Sampling for particulate cobalt is best conducted according to AS3640, using a mixed cellulose ester filter with nominal pore size of 0.8 µm. The filters can then be analysed using AAS or ICP. If health surveillance is required, lung function tests, assessment of the heart and tests of the skin for dermatitis are some common assessments that can be performed.

One product that is made from cobalt is cobalt naphthenate. This can be a brown powder or blue-red solid, and is used in paint varnish or to bond rubber to steel and other substances. Inhalation of cobalt naphthenate can lead to asthma. Inhalation may also cause scarring of the lung tissue, and high-level exposure may damage the heart and even cause an enlarged thyroid (goitre). Repeated exposure can cause a loss of the sense of smell, affect the red blood cells, increase serum fat and reduce the ability of the body to burn sugar from the diet.

**Copper**

Historically, copper (Cu) has been extensively used. Indians of the Pacific Northwest were making items from copper as far back as 5000 BC, with Asians in about 4200 BC appreciating the greater workability it afforded once heated. Indeed, the Bronze Age (about 3000–1200 BC) was named after the change from stone-based weapons and tools to those of copper and its alloy bronze. Bronze is actually a combination of copper and tin. Copper is also used nowadays, either as the metal or its alloy brass. Brass consists of copper and zinc.

In the workplace, exposure to copper usually occurs from the metal or its oxides. The two oxides of copper are Cu$_2$O (cuprite) and CuO (tenorite). Exposure may occur during smelting and refining.

Once copper ore is reduced, blowing air through the molten metal can be used to refine it. This oxidises any other metals that are present as impurities; the oxides rise to the surface and can be skimmed off. Copper is also used as an insecticide and bactericide and in electroplating. Exposure usually does not present a high risk to workers, except possibly those who have a genetic condition known as Wilson's disease. With this disease, the body is unable to excrete excessive copper; therefore, occupational exposure may lead to problems.

The TWA for copper (dust and mist) is 1 mg.m$^{-3}$. For copper fume, it is 0.2 mg.m$^{-3}$. Occupational hygiene sampling and analysis is similar to that of the other metals, by collecting the inspirable fraction and analysing with AAS or ICP.

**Gold**

Gold (Au) is one of the earth’s precious metals and is found in nature mostly as the pure free metal. However, oxides of other metals are usually found with the gold (e.g. silver, arsenic and copper) and need to be removed. This is where occupational exposure may occur.

Cupellation is the process that is used to remove impurities by adding lead metal or lead oxide to the gold. Refinement of gold using a
method known as froth flotation can introduce other occupational hygiene hazards such as arsenic and sulphur. The process of froth flotation is also often followed by cyanidation, where the crushed ore is treated with sodium cyanide and calcium oxide to oxidise the gold to Au (I). An alternative method known as amalgamation introduces mercury to form liquid alloys (amalgams). The gold is recovered by distilling away the mercury. Gold does not have an occupational exposure standard. In its refinement, consideration must be given to the risk associated with exposure to the other metals.

**Lead and lead oxide**

Lead (Pb) can be extracted by roasting the ore galena (PbS) in an oxidation reaction. In fact, the ore is normally found with argentite (Ag₂S) impurities, which are then separated to obtain silver. To obtain lead, the PbS, lead (II) sulphide, is oxidised to lead (II) oxide (PbO) and lead (II) sulphate (PbSO₄). Some PbS is also left unchanged, so if the air supply is reduced, the PbS left unchanged reacts with the PbO and PbSO₄ to produce lead metal.

\[
3\text{PbS} \ (s) + 5\text{O}_2 \ (g) \rightarrow 2\text{PbO} \ (s) + \text{PbSO}_4 \ (s) + 2\text{SO}_2 \ (g) \\
2\text{PbO} \ (s) + \text{PbS} \ (s) \rightarrow 3\text{Pb} \ (l) + \text{SO}_2 \ (g) \\
\text{PbSO}_4 \ (s) + \text{PbS} \ (s) \rightarrow 2\text{Pb} \ (l) + 2\text{SO}_2 
\]

Lead forms three oxides — PbO, PbO₂ and Pb₃O₄. PbO is also known as massicot (orang-yellow) or litharge (red) and is used to glaze pottery or in the manufacture of flint glass. These are known as inorganic lead compounds. PbO₂ is used in lead-acid accumulators, while Pb₃O₄ is a pigment which has past uses in anti-rust paints and crystal glass.

Another use of lead occurs in its organic state, in the compound lead tetraethyl or tetraethyl lead, Pb(CH₃)₄, that is added to leaded petrol as an antiknock agent. This gives rise to the risk of lead compounds escaping in the car exhaust and is a potential source of pollution wherever large numbers of cars are used. The use of unleaded fuel in new cars has been introduced to combat this. Cases of abnormal exposure to lead have been reported in moonshine-whisky drinkers due to the lead solder used to construct the stills.

Some industries where exposure to inorganic lead occur are:

- battery manufacture (lead-acid plates) and reclamation
- radiator repair
- propeller grinding
- lead lighting
- spraying with lead-based paints
- sanding or torch-cutting lead-painted metals and timber, such as with Queenslander houses painted prior to the 1950s or bridges, which used compounds such as PbSO₄, PbCrO₄ and PbCO₃ as pigments (modern paints contain little or no lead)
- gold or silver laboratory assayers
- indoor shooting gallery and rifle range operators.

The use of lead dates back to antiquity. The Romans used lead on an extensive scale for water pipes, linings and cooking utensils. Since lead will dissolve to some extent in water, lead poisoning became a common occurrence.

Lead has a reputation for its toxicological effects. It accumulates in the body. Therefore, exposure to small doses over a long period can affect a worker just as much as a high dose over a short period. Indeed, exposure to lead can be fatal, although usually the effects are not. The chronic effects of exposure to low levels of lead include:

- decreased intelligence in children
- neurobehavioural effects on children
- storage of lead in the bone and blood.
In its most acute form, lead poisoning results in brain damage which presents as mental impairment and personality changes. In less acute cases, there are abdominal pains accompanied by cramps, vomiting, weight loss and tiredness. In its least severe form, the result is anaemia, tiredness and irritability. The toxicology of lead exposure relates to the Pb (II) cation, which has the major effect of inhibiting the synthesis of haemoglobin.

The major route of entry for lead is through inhalation of dust and fume, although some is ingested following the lung clearance mechanisms. Inorganic lead is quite poorly absorbed by the gut and only about 10 per cent of the ingested dose is taken up by the body. The rate of absorption depends on other metals in the gut, particularly calcium and iron. With inhalatory exposure, the degree of uptake depends on the size of particulate and its solubility, with about 40 per cent of inhaled lead being absorbed. Organic lead compounds are absorbed through the skin.

Excretion of lead occurs primarily through the kidneys but small amounts are also lost through the bile, sweat and milk.

The bodily systems affected include the blood (haematopoietic) system, resulting in anaemia. Anaemia is seen only in inorganic lead poisoning and occurs late in the disease. Early symptoms of lead poisoning include abdominal pain, constipation and vomiting. A blue line on the gums due to the deposition of lead sulphide is occasionally seen. Lead is also a neurotoxin — affecting the intellectual development in the young, decreasing nerve conduction velocity and causing brain damage.

Organic lead poisoning may result from exposure to tetraethyl lead. The symptoms of organic lead poisoning differ from those of inorganic poisoning in that psychiatric manifestations, such as disturbances in sleep patterns, vertigo, headache, tremor, hyper-excitability and pain, are more common than with inorganic lead poisoning.

In Australia, the TWA for inorganic lead dust and fume is 0.15 mg.m$^{-3}$. Atmospheric monitoring can be conducted using inspirable dust monitoring techniques. Typically, an IOM or UKAEA sampling head is used, although a special one-hole lead-sampling head has been designed for collection of lead fume (Figure 5.1). The filters are typically mixed cellulose ester and are acid-digested before analysis by AAS or ICP.

Health surveillance for workers exposed to lead should be conducted before starting work in the lead process. Biological monitoring should be carried out within a month of work commencing. More health surveillance may be required three months after starting work and then again after six months. There are other reasons why biological monitoring for lead exposure should be conducted. These are:

- if an accidental uptake of lead is suspected
- if workplace control of the lead hazards has failed
- if work task factors might still result in an increased exposure to lead
- if workers have shown a past history of excessive exposure to lead
- if respiratory protective equipment is the only control used.

Blood lead levels are the usual type of biological monitoring. In order to determine whether a worker is at risk, blood lead action levels are used. Biological monitoring of lead workers is based on a test of lead absorption and a test that measures its metabolic effect. This can be either urinary ALA ($\delta$-amino lavulinic acid) or the red cell protoporphyrin concentration (zinc protoporphyrins or ZPP). Urinary tests for lead are the least preferred method, since the excretion of lead from compartments in the body occurs at different rates. Blood tests give the most reliable indicator of exposure.
As a general rule, lead workers’ blood lead levels should be maintained at less than 2.4 \( \mu \text{mol.L}^{-1} \). Obviously, these levels may differ for susceptible persons (e.g. women of childbearing age, pregnant women and children). If a worker has three successive blood lead estimations of more than 2.4 \( \mu \text{mol.L}^{-1} \) or one blood lead estimation more than 2.7 \( \mu \text{mol.L}^{-1} \), the worker should be removed from lead work and maintained under medical surveillance until the level falls below 2.4 \( \mu \text{mol.L}^{-1} \). If a blood lead level is more than 3.1 \( \mu \text{mol.L}^{-1} \), the worker must be removed from all work and maintained under medical surveillance until the blood lead level falls well below 2.4 \( \mu \text{mol.L}^{-1} \). If lead poisoning is suspected or confirmed, a chelating agent such as calcium EDTA and penicillamine (for adults) may be administered (only in hospital under supervised conditions) to bind with the lead and allow for removal from the body.

**Manganese**

Manganese (Mn) is an essential element within the human body but exposures that lie outside the optimal concentration window can be devastating. Manganese is a reddish-grey or silvery, brittle, metallic substance. It is used as an alloy in steel, to make dry cell batteries and in potassium permanganate.

Exposure typically occurs through inhalation of dust and fume, which can occur in the mining and smelting of ore or the alloy of manganese with steel, aluminium and cast iron. Because of its reddish colour, manganese dioxide is used to colour bricks. The initial effects of exposure include reduction in appetite, weakness and fatigue.

If exposure continues, it can cause permanent brain damage, and manifest with changes in speech, a loss of facial expression, personality changes, difficulty coordinating...
muscles, balance difficulties, twitching and tremors. The later symptoms are identical to Parkinson’s disease.

Exposure to manganese fume can result in metal fume fever. This ailment causes symptoms similar to the flu, with chills, fever and aching muscles. Manganese’s high molecular weight can also cause damage to the kidneys and liver.

The occupational exposure standard (TWA) for manganese fume is 1 mg.m\(^{-3}\). For the dust and compounds of manganese, it is 5 mg.m\(^{-3}\). Sampling for the inspirable fraction is according to AS3640 and analysis of filters by AAS or ICP is normal. Health surveillance for exposure to manganese typically involves a complete examination of the nervous system, blood count and kidney function tests.

**Mercury**

Mercury (Hg) is an interesting metal, in so much as it is the only metal that is liquid at room temperature. Its chemical symbol, Hg, originates from the word ‘hydrargyrum’. Mercury is formed from the heating or oxidation of the ore cinnabar (HgS) with lime (CaO).

\[
\begin{align*}
\text{HgS (s)} + \text{O}_2 (g) & \rightarrow \text{SO}_2 (g) + \text{Hg} \\
4\text{HgS (s)} + 4\text{CaO (s)} & \rightarrow 4\text{Hg} + 3\text{CaS (s)} + \text{CaSO}_4 (s)
\end{align*}
\]

At present, mercury has applications in scientific and electrical equipment (e.g. thermometers, manometers and barometers) and in metallurgical plant processes (pressure pumps). Organic mercury compounds are used as an anti-slime agent in papermaking and as seed dressings to prevent the spread of fungicidal seed diseases. Inorganic mercury compounds which have an industrial use include the nitrate which is used in ‘carrotting’ of rabbit fur to form felt for hats and the red oxide used in manufacturing anti-fouling paints which are applied to the hulls of ships.

The effects of exposure to mercury depend upon its chemical form. For instance, mercury (I) chloride (calomel or Hg\(_2\)Cl\(_2\)) was historically used as a purgative. Until recently, dental fillings used an amalgam of mercury with gold or silver.

If inhaled, only a tiny amount of inorganic mercury is absorbed into the bloodstream. Therefore, inorganic mercury should present only a minor risk. But history shows otherwise; in the early days of the industrial revolution, mercury (II) nitrate, Hg(NO\(_3\))\(_2\), was used to soften fur in the making of felt hats. The Mad Hatter of Lewis Carroll’s *Alice in Wonderland* must have been exposed to inorganic mercury, as he exhibits the typical effects on the central nervous system: mental effects and shakes.

The different forms of organic mercury, such as methylmercury (CH\(_3\)Hg), and other organomercury compounds, such as the mould-preventative phenylmercury acetate used in fertilisers, are much more dangerous. More than 90 per cent of the intake of methylmercury is absorbed into the bloodstream.

From an environmental perspective, organic mercury is a major concern. It is bioconcentrated in the food chain and fish and shellfish can concentrate mercury from the water to toxic levels. There have been several recorded instances of mercury poisoning, of which the most well known occurred at Minamata Bay, Japan, in 1952. The mercury source was a plant effluent. This effluent affected several hundred people, including unborn children. In other cases (Iraq in 1961, Pakistan in 1963 and Guatemala in 1966), people were poisoned by seed grains that had been treated with organomercurial preservatives.

The risk associated with mercury arises during the mining and recovery of the metal from ore and during the manufacture of compounds from the metal. Since mercury evaporates at room temperature it may also be a hazard if it escapes (for instance, breakage of
a thermometer). Mercury can also penetrate through the skin.

Approximately 80 per cent of inhaled mercury vapour is absorbed by the lungs, although the rate of absorption will depend on the particle size and chemical composition of the mercury. Elemental mercury is able to cross the blood–brain barrier and also crosses the placenta. While inorganic mercury compounds do not cross the blood–brain barrier, they are widely distributed in other tissues.

The main adverse health effects associated with excessive exposure to mercury include damage to the kidneys, liver and brain. The symptoms of acute poisoning include cough, fever, nausea, vomiting and a feeling of tightness in the chest. The most serious effects of chronic mercury exposure relate to its impact on the nervous system and the kidneys. The characteristic sign of mercury poisoning is the production of a tremor, known commonly as the hatter’s shakes. Along with the tremor, the person’s handwriting becomes irregular and unintelligible and speech disorders may occur.

The occupational exposure standard for mercury depends on its chemical composition. Elemental and divalent compounds of mercury have a TWA of 0.025 mg.m\(^{-3}\). Inorganic mercury compounds have a TWA of 0.1 mg.m\(^{-3}\) and alkyl mercury compounds have a TWA of 0.01 mg.m\(^{-3}\).

Mercury can be monitored using indicator stain tubes, although these present problems since their sensitivity is not below the occupational exposure standard. A direct-reading instrument may also be used to monitor for mercury.

Urinary mercury concentration is the method used to determine workers’ actual exposure to mercury. However, since there is a marked variation in the excretion of mercury from the body, the sample should be collected at the same time as an airborne sample. Background levels may be expected due to diet (e.g. fish consumption) although background levels are usually less than 0.1 mg.L\(^{-1}\). Urinary mercury concentrations above 0.3 mg.L\(^{-1}\) are excessive.

**Nickel**

Nickel (Ni) is a silvery-white metal that forms a large number of compounds. For instance, it is used in manufacturing alloys (such as stainless steel (iron, chromium and nickel), nickel-copper and nickel-chromium), manufacturing chemical process equipment, coins, magnets, batteries, bimetallic strips, electroplating, welding rods and electrodes and the aerospace and automotive industries.

The main compounds of nickel are either nickel metal, nickel soluble compounds, nickel carbonyl or nickel sulphide fume and dust which occur when the ore is roasted. In its metallic form nickel acts as a sensitiser. If exposure to the skin occurs, it may result in a condition known as nickel itch. You may see this with people who wear cheap jewellery and watches. The symptoms are usually localised, with itching, redness and a rash. A lung allergy may also occur. This manifests with asthmatic-like effects, with coughing, shortness of breath and fluid in the lungs.

Nickel also reacts with other substances to form compounds such as nickel carbonyl, nickel hydroxide, nickel sulphide, nickel cyanide and nickel ammonium sulphate. Nickel ammonium sulphate is a green odourless powder that can be used in electroplating. It can cause sensitisation, as well as damaging the lungs. High-level exposure or repeated lower exposure may also damage the heart, liver and kidneys.

Nickel carbonyl is used when refining nickel ore and as a catalyst in chemical reactions. It is a pale yellow liquid with a musty odour. Exposure may occur through inhalation or through the skin. The effects of exposure include headache, dizziness and nausea. In severe cases it may cause death from
respiratory and heart failure. It may also cause a skin allergy.

Anhydrous nickel cyanide is a yellow-brown powder although when it absorbs water, it may change to a green colour. It is used in metallurgy and for electroplating.

Nickel hydroxide is a green-coloured powder and may be present in the workplace as a dust or as a liquid in an acid solution.

Nickel sulphate exists as blue to blue-green crystals with a sweet taste. It is used to make other nickel compounds and as a mordant in dyeing, printing textiles, coatings and ceramics.

The roasting of nickel is recognised as a Category 1 human carcinogen. Repeated exposure to nickel and its compounds can cause cancers of the lung and nose. Nickel is also a potent skin sensitiser and many people exposed at work to the various forms of nickel have developed allergic dermatitis.

The occupational exposure standards (TWA) for exposure to nickel and its compounds are:

- **metallic nickel** — 1 mg.m\(^{-3}\)
- **soluble nickel compounds** — 0.1 mg.m\(^{-3}\)
- **nickel carbonyl** — 0.05 ppm
- **nickel sulphide roasting (fume and dust)** — 1 mg.m\(^{-3}\).

Osmium and osmium tetroxide

Osmium (Os) is a metal that is used to produce very hard alloys with other metals of the platinum group, for instance, fountain pen tips, instrument pivots and electrical contacts. Osmium tetroxide (OsO\(_4\)) is used to detect fingerprints, as a catalyst and to stain fatty tissue for microscope slides. The alloy of platinum and osmium is used in surgical implants such as pacemakers and replacement valves. The metal is lustrous, blue-white in colour, extremely hard and brittle even at high temperatures. It has the highest melting point of the platinum group.

The main occupational hygiene concern is associated with osmium tetroxide, a colourless or pale yellow solid with a very strong odour. It is a strong oxidising agent. Exposure to osmium tetroxide can result in severe burns to the skin and eyes. Prolonged exposure can lead to ulcers and even blindness. The vapours are irritating to the upper respiratory tract and lead to wheezing, coughing, tightness in the chest, sore throat and hoarseness. Due to this irritating effect, the eyes often are affected, with the worker suffering from blurred vision and seeing halos around lights.

The TWA for osmium tetroxide is 0.002 ppm. The STEL is 0.006 ppm. It can be sampled using a midget impinger.

Platinum

Platinum (Pt) is a precious, rare, white metal with unusual properties. It is heavier than gold, is virtually impossible to corrode and has a very high melting point.

It was used historically to make expensive cutlery, watch chains and coat buttons. In the early nineteenth century, it found use in gun parts, sophisticated batteries and fuel cells and the purification of hydrogen. It is currently
used to make coins and jewellery, in surgical and dental applications and in laboratory apparatus, to make drugs for cancer treatment, and to make computer and automotive equipment. Interestingly enough, platinum is also used in the catalytic converters of motor vehicles to convert carbon monoxide into carbon dioxide and water.

From a risk management perspective, exposure to platinum can be assessed either as the metal or as soluble salts of platinum. The TWA for metallic platinum is 1 mg.m$^{-3}$. For soluble salts it is 0.002 mg.m$^{-3}$. It is sampled as the inspirable fraction according to AS3640 and analysed for the specific metal or compound.

**Selenium**

Selenium (Se) is a black, grey or red odourless metalloid that is used to manufacture electrodes, photographic exposure meters, anti-dandruff shampoos and rectifiers for home entertainment equipment and as a pigment for ruby glass, paints and dyes. It is also used in veterinary medicine and as a fungicide and insecticide.

Selenium is also an essential metal for the human body, acting as an antioxidant. It is required for tissue elasticity and effective functioning of the pancreas.

With occupational exposure to selenium, the main concerns are its compounds, especially selenium dioxide and hydrogen selenide which can cause eye irritation. Inhalation of selenium dust or mist, selenium dioxide or hydrogen selenide can irritate the nose, throat and upper respiratory tract. Exposure can cause headache, dizziness and general malaise. High concentrations of selenium dioxide can cause bronchial spasms, symptoms of asphyxiation and bronchitis.

While ingestion of selenium or its compounds is unusual, high-level exposures through this route of entry can cause pulmonary oedema and lung lesions. Acute oral exposures can cause aches and pains, irritability, chills and tremors. If exposure continues, a metallic taste is apparent, with ‘garlicky breath’, fatigue, increased dental cavities, loss of nails and hair, irritability and, sometimes, depression. Repeated higher exposures to selenium also may cause liver damage.

The TWA for selenium compounds (excluding hydrogen selenide) is 0.1 mg.m$^{-3}$. The TWA for hydrogen selenide is 0.16 mg.m$^{-3}$. To sample for the selenium particulate, inspirable dust monitoring is used with the filters analysed by AAS. With hydrogen selenide, sampling is conducted using an impinger.

**Silver**

Silver (Ag) is usually found with lead, although it may also be found naturally as the metal or as the insoluble chloride salt AgCl (cerargyrite or horn silver). To obtain silver from ore, it is roasted in oxygen to form SO$_2$ and Ag$_2$O. This is followed by a reduction reaction with carbon to form Ag and CO$_2$.

Silver and its compounds are used in black and white photography, jewellery, X-ray film development, trinkets, mirrors, electroplating, cutlery and silverware. Silver is a brilliant, soft, white metal.

Exposure to fine silver dust or fume can lead to a blue or grey staining of the eyes, mouth, throat, internal organs and skin. This occurs slowly and may take years to develop. Once present, it does not go away. Skin contact can cause silver to become embedded in small cuts in the skin, forming a permanent tattoo.

A compound of silver, silver nitrate is a colourless, odourless solid that is also used in photography, silver plating, chemical reactions and mirror manufacturing and as an antiseptic. Exposure may cause irritation and burns to the eyes and skin. It can also cause the colour change described earlier.
In Australia, the TWA for metallic silver is \(0.1 \text{ mg.m}^{-3}\). For the soluble silver compounds, it is \(0.01 \text{ mg.m}^{-3}\). Sampling for silver dust is best conducted using inspirable dust sampling techniques, with the filters analysed by ICP. For soluble silver compounds, the filters are analysed with plasma emission spectroscopy.

**Thallium**

Thallium (Tb) is a solid, bluish-white metal. It has no odour or taste and gives no warning of its existence in the workplace. One of the properties that makes thallium useful is a change in electrical conductivity that occurs to thallium sulphide when exposed to infrared light. Thallium forms many isotopes. Natural thallium is a mixture of two isotopes. It is used in the making of semiconductors, in photo-electric equipment such as photocells and in lenses and thermometers. The sulphate is used as a rodenticide and ant killer, and thallium bromide-iodide crystals are used as infrared detectors. Historically, thallium was used in the treatment of ringworm and other skin infections.

Exposure to thallium occurs chiefly through inhalation, although absorption through the skin may also be a significant source of exposure. The symptoms of exposure to thallium often do not show until some days after exposure. The effects can include weakness, irritability, pain and pins and needles in the arms and legs, confusion and mood changes, hair loss, loss of vision and permanent brain damage. High-level exposures can cause tremor, convulsions, hallucinations, coma and death.

In Australia, the TWA for thallium is \(0.1 \text{ mg.m}^{-3}\). Occupational hygiene monitoring may be conducted using the inspirable fraction; however, since skin absorption can be a significant source of exposure, biological monitoring of urine may be more appropriate to determine the body burden.

**Tin**

Metallic tin (Sa) is obtained from the mineral cassiterite (SnO\(_2\)). The characteristics of tin which make it useful are its ability to alloy with most other metals, its low melting point, its low toxicity and that it does not corrode. Therefore, tin sees applications as an ingredient of solder, in containers for food and drink, as a component of pewter and bronze and in ‘lead-free’ plumbing pipes.

Tin chloride (SnCl\(_2\).H\(_2\)O) is used as a mordant in calico printing. The salts of tin are also sprayed onto glass to make electrically conductive coatings. These have been used for panel lighting and for frost-free windscreens. Trialkyl and triaryl tin compounds are used as biocides.

In Australia, the TWA for metallic tin is \(2 \text{ mg.m}^{-3}\). For organic tin compounds (e.g. the alkyl products) the TWA is \(0.1 \text{ mg.m}^{-3}\) with a STEL of \(0.2 \text{ mg.m}^{-3}\). Exposure through the skin may be of additional concern with organic compounds of tin. With tin oxides and inorganic compounds, the TWA is \(2 \text{ mg.m}^{-3}\).

**Titanium**

Titanium (Ti) is a light, strong, ductile and corrosion-resistant metal that is often alloyed with other metals such as aluminium, tin, iron, vanadium, chromium and molybdenum to form light but strong items. Some typical applications of metallic titanium include aircraft and aerospace, ordnance hardware (e.g. mortar base plates), sports products (e.g. golf clubs, tennis racquets, cycling components, snow-skiing poles), surgical implants, dental alloys, spectacle frames and jewellery.

As a metal, titanium is relatively inert. It does form other compounds, though. Titanium dioxide (TiO\(_2\)) is used as a pigment or as an opacifier for products such as paint, plastics, paper, inks, fibres, food and cosmetics. The
TWA for titanium dioxide is 10 mg.m\(^{-3}\). Another compound, titanium tetrachloride (TiCl\(_4\)), is a colourless or light yellow, fuming liquid with a pungent odour. It is mainly used to make iridescent glass, artificial pearls, smokescreens and as a catalyst. Exposure to titanium tetrachloride can cause irritation and burns to the eyes, skin and upper respiratory tract although this is mostly due to the chloride components.

**Tungsten**

Metalllic tungsten (W) lies in the same chemical group as chromium and molybdenum. It is used for filaments in electric lamps, television tubes, electrical contact points for car distributors, heating elements for electrical furnaces and high-speed tool steels. Tungsten carbide is important to the metalworking, mining and petroleum industries. Calcium and magnesium tungstates are widely used in fluorescent lighting. Tungsten salts are used in the chemical and tanning industries.

Exposure to tungsten metal does not normally present a risk to workers; however, all tungsten compounds should be regarded as highly toxic. Insoluble tungsten compounds have a TWA of 5 mg.m\(^{-3}\) and a STEL of 10 mg.m\(^{-3}\). For soluble compounds containing tungsten, the TWA is 1 mg.m\(^{-3}\) and the STEL is 3 mg.m\(^{-3}\).

**Vanadium**

Vanadium (Vn) is a grey or white shiny powder or solid metal that is mined in South Africa, Russia and China. Vanadium is an essential metal, which helps control some enzyme systems in the human body. It is used to make steel alloys, for X-ray equipment, to manufacture sulphuric acid and synthetic rubber, in nuclear applications, to produce rust-resistant, spring, and high-speed tool steels, in ceramics (vanadium pentoxide), as a mordant in dyeing and printing fabrics and in the manufacture of aniline black.

Occupational exposure to vanadium mainly occurs when fossil fuel oils rich in vanadium are burnt. The remaining ash contains vanadium and workers who clean the boilers are at risk of exposure. This may occur during a shutdown of process industries such as an oil refinery. Vanadium is also used in the manufacture of pigment paints and printing inks, and is used in association with titanium in the manufacture of jet engines and air frames. Vanadium is excreted in the urine and levels correlate well with airborne vanadium.

The health effects from exposure to vanadium include diarrhoea and vomiting. Dust particles cause irritation to the skin, eyes and lungs. The TWA for vanadium pentoxide (measured as the respirable fraction of dust and fume) is 0.05 mg.m\(^{-3}\).

**Zinc**

Metallic zinc (Zn) is a soft, white metal with a blue tinge. It has applications as a coating on iron and steel, in brass metal alloys and as a dust in making paint and dyes. It also reacts with other elements to form substances such as zinc oxide (ZnO) and zinc sulphate (ZnS). By itself, zinc metal is unlikely to cause overexposure since it is an essential metal. However, if heated it may give off zinc oxide fume, which can cause health effects. Also, during the refining process, cadmium can be released.

Zinc oxide is a yellowish powder that is used as a fungicide and as pigment in rubber products, paints, lacquers, varnishes, ceramics and cosmetics. Exposure to zinc oxide can result in a flu-like illness known as metal fume fever.

The symptoms include a metallic taste in the mouth, headache, cough, shortness of breath, aches and chills, an upset stomach and chest pain. Repeated high exposures may cause ulcer symptoms and affect liver function.
Metal fume fever often occurs in welders who are soldering, brazing, cutting, forging, melting and casting with elements of zinc, copper or iron. Although metal fume fever can occur following exposure to several metal oxide fumes (this was identified earlier in this chapter), zinc oxide is the most frequent cause of the syndrome. Arc welding of galvanised steel is the most common source of exposure.

The production of zinc oxide fume requires heating elemental zinc or zinc-containing alloys to elevated temperatures, which results in volatilisation of zinc. This causes the vapours to rapidly oxidise in air, forming very small particles (with an aerodynamic equivalent diameter of less than 0.5 µm). The particles are then absorbed in the lower respiratory tract causing inflammation and tissue damage.

Metal fume fever is also known as Monday fever, brass chills, foundry fever, welder’s ague and smelter chills. It typically affects the new worker. Those who have experienced exposure to zinc oxide fume tend to be prone to repeat attacks of metal fume fever, especially if they have not been exposed for the previous few days.

The clinical signs of metal fume fever manifest within four to eight hours after exposure with a number of non-specific complaints. These include a sweet or metallic taste in the mouth, fever, chills, nausea, headache, fatigue and abdominal discomfort. Muscle aches and joint pains may also occur 8–12 hours post-exposure and may be accompanied by a constricted, dry or irritated throat, which may give rise to hoarseness and coughing. The symptoms usually resolve spontaneously after 24–48 hours, resembling an acute viral syndrome. The next morning, most of the symptoms have abated and the worker is able to return to work, albeit feeling slightly hungover. No long-term complications or residual effects due to zinc oxide exposure are known to exist at the present time.

The aetiology of metal fume fever is believed to be an immunological reaction that occurs when the freshly formed metal oxide fumes injure the cells lining the airways. This causes lung proteins to modify. The modified proteins act as allergens and generate an allergen–antibody reaction, resulting in an allergic reaction.

Another compound of zinc is zinc potassium chromate. This substance is a Category 1 carcinogen and may enter the body through inhalation or the skin. It is a yellow powder that has been used both as a rust inhibitor in metal paints and as an artists’ colour. Repeated exposure can cause a hole in the nasal septa, with nosebleeds and sores the earlier signs. Exposure can irritate the skin, causing rash or skin ulcers. It can also trigger a skin allergy, so that even low exposures cause rash.

Zinc sulphate is a colourless, crystalline powder that is used for manufacturing rayon and as a wood preservative. Contact with zinc sulphate may burn the eyes or skin. In Australia, the occupational exposure standards for zinc and its compounds are:

- **zinc oxide dust** — 10 mg.m\(^{-3}\) TWA
- **zinc oxide fume** — 5 mg.m\(^{-3}\) TWA and 10 mg.m\(^{-3}\) STEL
- **zinc chromate** — 0.01 mg.m\(^{-3}\)
- **zinc chloride** — 1 mg.m\(^{-3}\).

Occupational hygiene sampling for zinc fume, oxide or the chloride particulate is conducted using inspirable dust sampling techniques according to AS3640. Care should be taken in the selection of the filter, to ensure that the nominal pore size is sufficient to collect the dust or fume. Usually, the collection of fume requires a filter with nominal pore size of 0.8 µm or less. The filter is then analysed in a laboratory, usually by AAS. With zinc chromates, a PVC filter with low moisture pick-up is used.
SUMMARY

Many metals are essential to maintain homeostasis of the body. However, some can place workers’ health at risk, causing adverse health effects and polluting the environment.

The major route of entry of most metals and metalloids is through inhalation of the dust or fume. Exposure via ingestion or through the skin occurs less frequently.

Some examples of occupationally significant metals include aluminium, antimony, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, tin, vanadium and zinc.

BIBLIOGRAPHY AND FURTHER READING

SKC 1993, SKC Comprehensive Catalog & Air Sampling Guide, SKC Inc., USA
In the workplace, some of the craftiest occupational hygiene hazards are chemical contaminants (including gases and vapours). With their weak bonds between atoms and molecules, these chemical contaminants have a unique characteristic of pervading even the smallest space. The result may be from the displacement of oxygen, or the toxicity of the contaminant can result in adverse health effects. Gases and vapours can be introduced into the workplace as the result of a particular process, for instance, the chlorination of water in swimming pools and water treatment plants using chlorine gas (Cl₂) or sodium hypochlorite. Other times, exposure may be through an unintended process or as a by-product. The presence of methane (CH₄) in coalmines became a hazard in the early part of the seventeenth century when deep shafts were first dug into coal seams. The gas was formed in pockets in the seam and escaped when the coal was being mined.

Vapours arise where a liquid exhibits a significant vapour pressure. This allows molecules toward the top of the liquid to escape and transfer to the gaseous state. The most common vapours in the workplace arise from solvents. Solvents are used in industry for a variety of purposes. Some of the more important uses are:

- for extracting oils and fats
- in paints
- in varnishes
- in polishes
- for cleaning of materials and fabrics.

Dry-cleaning, for instance, utilises the chlorinated hydrocarbon, perchlorethylene. Solvents may also be used for extracting medicinal materials from bones, seeds and nuts, and for degreasing. Chemical reactions may be better facilitated by the addition of solvents that act to dissolve the specific chemical reagents.

This chapter discusses the nature of vapours and gases and will highlight the health effects from exposure, air monitoring techniques and analytical methods. It provides an overview of specific gases and vapours, with an emphasis on commonly found contaminants such as asphyxiants, irritants, toxic gases and vapours.

**THE NATURE OF GASES AND VAPOURS**

Airborne chemical contaminants such as gases and vapours have unique characteristics that impact on the risk they present from exposure. These properties are quite distinct from those of other airborne contaminants such as particulate and dust, which were discussed in Chapter 4. The first characteristic relates to the physical structure of gases and vapours and
their ability to freely permeate throughout an area. This has drawbacks in restricting the movement of a contaminant from one area to another but can be used to advantage when controlling contaminants through ventilation. The capture velocity of gases and vapours is usually low and the contaminant can be swept along with existing air. Thus, gases are usually measured volumetrically. Vapours can be represented either volumetrically or as a mass per volume.

The second characteristic of gases and vapours that distinguishes them from other occupational hygiene hazards is the odour. Many gases and vapours have an odour threshold or distinctive odour that can assist in their identification as a hazard. Unfortunately, although it is useful as a warning signal, it does not always relate to the concentration of contaminant or its potential risk associated with its toxicity.

Thirdly, unlike dusts and particulate, many gases and vapours can enter the body by absorption through the skin. This additional route of entry needs to be considered when evaluating the risk of exposure. Often, it will not be adequate to merely assess exposure through the inhalation route. Solvent vapours in particular are notorious for defatting the skin, causing the lipid layer of the epidermis to be removed. Others can cause a hypersensitivity or allergic reaction in the skin. Each of these features of gases and vapours will now be discussed.

**Physical structure and units of measurement**

Gases are essentially fluids that expand to occupy the space or volume in which they are confined. This concept is due to the weak bonds between atoms or molecules and the ability of gas to move freely, without the confines of a rigid structure that binds solids. Because of this, gases are usually measured volumetrically or as a percentage (%) of the total environment. The standard units are %vol/vol or %v/v. In other words, the volume of a specific gas compared to the volume of the reference environment (usually air). For instance, air at 1 atmosphere (sea level) has about:

- **20.95 per cent oxygen (O₂)**
- **79 per cent nitrogen (N₂)**
- **0.03 per cent carbon dioxide (CO₂)**
- **trace amounts of other inert gases.**

Notice that the v/v or vol/vol has been removed in this expression. In every day practice, it is normal to express gases simply as a percentage, although technically speaking we are referring to the volumetric concentration. Vapours can be measured either volumetrically (%v/v) or as a weight per volume (%w/v). This difference arises from the source of the vapour. Vapours are defined as the gaseous form of a substance that is usually in the solid or liquid state at room temperature. In reality, most organic vapours such as xylene, toluene or benzene are liquid at room temperature.

Where a substance converts directly from the solid to gaseous state, this is known as sublimation. The apparent ‘dissolving’ of mothballs containing naphthalene over a period is actually due to sublimation. Since the vapour’s origin is measured as a mass, the resultant vapour is expressed as milligrams of the contaminant per cubic metre of air (mg.m⁻³).

### Equation 6.1

\[
\% = \frac{\text{mg.m}^{-3} \times 24.4 \times 10^4}{\text{MW}}
\]

Where:

- \(\text{mg.m}^{-3}\) is concentration of the contaminant
- \(\text{MW}\) is molecular weight
- 24.4 is molar volume in litres
- at 25°C and 1 atmosphere
In reality, some simple arithmetic can transform mg.m$^{-3}$ to a percentage, if the molecular weight (MW) of the contaminant is known. This equation, introduced in Chapter 1, converts mg.m$^{-3}$ to ppm (parts per million). Remembering that 1 per cent is equal to 10 000 ppm, Equation 6.1 simplifies the conversion from mg.m$^{-3}$ to a percentage.

**Odours**

Many gases and vapours have a handy characteristic that is useful in recognising the hazard — an odour. Odour perception can be an effective hazard identification technique, although it should not be relied upon for quantification of the risk associated with exposure to the contaminant. The limitations of odour thresholds include:

- **the range of odour perception amongst individuals will vary** (what one worker can perceive, another may not)
- **the inability to confidently define a relationship between the presence or absence of an odour and the extent of risk to workers’ health**
- **interference from other substances**
- **the development of olfactory fatigue** (dulling or deadening of the sense of smell) that can occur after exposure to some contaminants; this condition is particularly prominent when a worker may be exposed to a strong odour initially, but after repeated or continued exposure the odour is completely undetectable.

Very often, the odour threshold of a contaminant is actually higher than the occupational exposure standard. Therefore, even if the worker were to detect the odour of the contaminant, exposure may have already caused damage to the body. For instance, n-hexane has an odour threshold of 130 ppm while its occupational exposure standard (TWA) is 20 ppm. Hydrogen sulphide (rotten egg gas) has an odour threshold of 0.0002 ppm and the occupational exposure standard (TWA) is 10 ppm. Some examples of odour thresholds are shown in Table 6.1.

**Table 6.1 Odour thresholds**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Odour threshold (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>0.0002</td>
</tr>
<tr>
<td>Ozone</td>
<td>0.01</td>
</tr>
<tr>
<td>Toluene</td>
<td>2</td>
</tr>
<tr>
<td>Xylene</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Dermal effects**

While we recognise that exposure to gases and vapours chiefly occurs through inhalation, the possibility of dermal or skin absorption of chemical contaminants should not be disregarded. Substances such as nitrobenzene, aniline and some pesticides can pass easily through the skin and be absorbed directly into the tissues of the body. It has been recognised that mixing and spraying pesticides during windy conditions presents a higher risk than when the air is still. This is due to the spray drift accumulating on the skin and being absorbed into the body. In the agricultural industry, there have been several instances of farmers suffering severe ill health after spraying pesticides from a leaking backpack holding the chemical. As the backpack leaked, the chemical was absorbed into the farmers’ clothing and then directly into their skin.

Skin absorption of chemical contaminants typically occurs where a substance is splashed onto the skin or the skin is immersed directly into the substance. The effect may be acute (i.e. spillage of corrosive substances)
or chronic (i.e. the narcotic effects of exposure to organic solvents). In rare cases, if the airborne concentration of a contaminant is sufficient, it may also be absorbed through the skin.

It is important to note that some guidance about skin absorption is available in the national exposure standards. A notation of ‘Sk’ in column 6 of the NOHSC exposure standards document indicates that absorption through the skin may be a significant source of exposure. This form of skin absorption can occur in several ways:

- splashing directly onto the skin or mucus membranes
- splashing onto clothing followed by absorption through the skin
- absorption directly from the vapour where the atmospheric concentration is high (although this rarely occurs).

In some cases, other substances or mechanisms may also accelerate skin absorption. For instance, solvents may increase the rate of uptake through the skin by defatting the lipid layer of the epidermis, making the dermis more susceptible. It has also been reported that some forms of barrier creams could contribute to the overall absorption of substances.

Sweat can also contribute to an increased uptake of chemical contaminants. Wearing impermeable gloves (e.g. PVC, nitrile, butyl rubber) in warm conditions can cause the hands to perspire. This additional heat and water causes occlusion, where the substance is close to the skin and quickly absorbed through its surface. In cases where skin absorption of a substance presents a risk to workers’ health, it is always wise to adopt biological monitoring techniques in addition to the air monitoring program. Some occupational examples where skin exposure should be considered include:

- the use of 4,4’-methylene bis (2-chloroaniline) or MOCA, which is used in the manufacture of skateboard wheels and hard plastics, and is suspected of causing bladder cancer
- hydrogen cyanide (HCN), which is a component in the production of isocyanates
- polychlorinated biphenyls (PCB), which are clear to yellow-coloured solids or liquids that were used as electrical insulators (e.g. transformers, capacitors); are notorious for being absorbed through both inhalation and the skin; are a suspected human carcinogen; can cause an acne-like skin rash; and can damage the liver.

Categorising gases

In the workplace and indeed in everyday life, we are exposed to myriad gases. How do we possibly decide which gases can harm and which will be exhaled without causing damage to the human body? A good starting point is to categorise gases according to health effects. Three available options are:

- asphyxiants
- irritants
- toxics.

Simple asphyxiants are gases that can cause a reduction in oxygen concentration by displacement or dilution. Most are odourless, such as carbon dioxide (CO₂) or nitrogen (N₂). Chemical asphyxiants, on the other hand, can be present in relatively low concentrations but affect the body’s mechanism for oxygen uptake or distribution. Carbon monoxide (CO), a by-product of incomplete combustion, is a typical example of a chemical asphyxiant. Many cases of accidental or intentional carbon monoxide poisoning have been documented, both in the workplace and in the community.
Exposure to irritants will chiefly affect the upper respiratory tract, resulting in uncomfortable burning or stinging. Pyrolysis of thermoplastics such as polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polystyrene (PS) and polytetrafluoroethylene (PTFE) can emit toxic and irritant gases. Of course, the exact nature of the gases will depend on the starting plastic and processing temperature.

Toxics can be broadly described as those gases that can cause local or systemic effects in the body and have an occupational exposure standard.

The movement of gases and vapours in the body is influenced by their partial pressure. Gases move from areas of high pressure to areas of lower pressure. Gases will also diffuse into liquids. Therefore, their water-solubility is an important factor that will impinge on their transportation and excretion throughout the body. Once gas has passed through the alveolar capillaries, it must be transported through a medium (e.g. haemoglobin in blood or dissolved into the plasma of blood or the interstitial fluids). However, the rate of gas exchange may also be limited by environmental conditions.

Once the gas enters the conducting or respiratory zone of the respiratory system, it can be absorbed in the following ways:

- **by exchange at the body surface** (e.g. mucous membranes of the nose and pharynx), where the gas diffuses over a thin, moist respiratory surface
- **by exchange within the trachea and its branches**
- **by passing across the alveolar tissue**, where it is exchanged between the medium and blood vessels — this action will depend on the pressure difference (continual gradient) across the tissue.

In the alveoli, the exchange of gas is driven by its partial pressure gradient. Oxygen passively diffuses from alveolar air spaces, through interstitial fluid into lung capillaries. In normal respiration, carbon dioxide, driven by its partial pressures, diffuses in the reverse direction. Gases also dissolve into the plasma of blood.

### PHYSIOLOGICAL EFFECTS OF EXPOSURE TO GASES

As with other airborne contaminants such as metals, dusts and particulate, the magnitude of risk associated with exposure to gases is dependent upon the chemical composition and dose. The chemical composition will determine the:

- **level of solubility in different areas of the body**
- **the substance’s affinity for certain tissues or parts of the body**
- **the target organ**.

For instance, ammonia (NH₃) gas, found in large refrigeration plants, is particularly water-soluble. Therefore, the effects of exposure present in the watery mucous membranes of the eyes, nose and throat. Lipophilic substances such as organic solvents are attracted to the lipid-layers of the skin and strip off this layer. Carbon disulphide (CS₂) vapour can affect the nervous system and the heart. Carbon monoxide has an affinity for haemoglobin in red blood cells that is some 250 times greater than oxygen!

### SIMPLE ASPHYXIANTS

In its barest form, a simple asphyxiant is defined as a gas that has the ability to displace
or dilute the normal oxygen concentration to a level that can place lives at risk. Since it is not the toxic effect of simple asphyxiants that present a hazard but their ability to reduce oxygen concentration, they are not assigned occupational exposure standards. Instead, the required levels of oxygen are specified. As a minimum level, the oxygen concentration should not fall below 18 per cent under normal atmospheric conditions.

If the atmospheric pressure is significantly higher or lower than normal conditions, the concentration of oxygen will vary according to Pascal's principle.

Blaise Pascal (1623–62) was a French philosopher and scientist. Pascal's principle states that pressure applied to a confined fluid increases the pressure throughout by the same amount. The pressure of the earth’s atmosphere (just like any fluid) decreases with decreased depth (or increased height). At sea level, the pressure is accepted as $1.013 \times 10^5$ N.m$^{-2}$, or 101 325 Pascals (Pa) or 1 atmosphere. Therefore, in conditions of higher atmospheric pressure (e.g. in deep underground mines or underwater diving) the partial pressure of oxygen increases. At high altitudes (decreased atmospheric pressure) the partial pressure of oxygen decreases.

### Table 6.2 Simple Asphyxiants

<table>
<thead>
<tr>
<th>Substance</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetylene</td>
<td>(C$_2$H$_2$)</td>
</tr>
<tr>
<td>Argon</td>
<td>(Ar)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>(CO$_2$)</td>
</tr>
<tr>
<td>Ethane</td>
<td>(C$_2$H$_6$)</td>
</tr>
<tr>
<td>Ethylene</td>
<td>(C$_2$H$_4$)</td>
</tr>
<tr>
<td>Helium</td>
<td>(He)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>(H$_2$)</td>
</tr>
<tr>
<td>Methane</td>
<td>(CH$_4$)</td>
</tr>
<tr>
<td>Neon</td>
<td>(Ne)</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>(N$_2$)</td>
</tr>
<tr>
<td>Propane</td>
<td>(C$_3$H$_8$)</td>
</tr>
<tr>
<td>Propylene</td>
<td>(C$_3$H$_6$)</td>
</tr>
</tbody>
</table>

Of these gases, only argon, helium, neon and nitrogen are not expected to present an explosion hazard. These types of gases are called inert, meaning they will not react with other gases or substances.

### Acetylene and argon

Acetylene (or ethyne) is used as a fuel for welding and cutting operations in metal fabrication and construction. It has the chemical formula H—C≡C—H, and is usually mixed with oxygen (hence the term oxyacetylene welding) to produce a blue-coloured flame that has a temperature in excess of 6000ºC. This is the hottest flame of all hydrocarbon gases.

Acetylene has a flammable range of 2.5–100 per cent, with a relative density of 0.9. According to dangerous goods classifications, acetylene is a Class 2.1 flammable gas.
Argon (Ar) is an inert gas (Class 2.2 nonflammable gas) that is used as a shielding gas in welding and cutting operations. Its most common application is in fabrication involving zirconium and titanium. It is also known as a noble gas. There are six noble gases that have the characteristics of being exceptionally stable, so that they almost never react with other elements. In the periodic table, they are the gases that make up Group 0 or the column furthest to the right of the table. Included are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Argon finds its major applications in colourful signs, gas-filled electric light bulbs and fluorescent tubes. It is also used in Geiger counters (Chapter 9).

**Carbon dioxide**

Carbon dioxide (CO₂) is a by-product of respiration and is used by plants in photosynthesis. It has gained notoriety as the main greenhouse gas associated with global warming. While carbon dioxide does absorb infrared radiation from the sun, it also has contributed to the overall heating of the earth. It has wide applications in industry, including:

- **gassing mineral waters and sweet beverages** (CO₂ is dissolved under pressure in the liquid to give a fizz and bitter taste)
- **deep-freezing of food** (snow or dry ice, solid CO₂, is passed over the food product in a deep-freeze, reaching a minimum temperature of −18°C)
- **thermoregulating pastry for sweets or the mincing of other food products** (the solid CO₂ absorbs heat as it changes from the solid to gaseous state)
- **maintaining low temperatures in catering lines** (e.g. airline meals and restaurants) for pre-cooked foods using dry ice

- **transporting refrigerated items** (using CO₂ pellets or ice bricks)
- **packaging food products to protect against bacterial growth.**

In general industry, carbon dioxide also finds applications in:

- **controlling the pH of wastewater** (gaseous CO₂ dissolves in water to form carbonic acid and its salts, leading to a small acidification of the industrial discharge)
- **atmosphere enrichment in greenhouses for the better nourishment of plants**
- **substituting the pollutant atmosphere containing sulphur dioxide (SO₂), which is associated with the heat treatment of magnesium and aluminium alloys**
- **as a fire-extinguisher media.**

High-risk areas for exposure include fermenting vats, breweries, mines, coke ovens, agricultural silos and silage pits. Although carbon dioxide is a simple asphyxiant, the NOHSC has set occupational exposure standards for normal operations and in coalmines. For most workplaces, the TWA is 5000 ppm and the STEL is 30 000 ppm. In coalmines, the TWA has been increased to 12 500 ppm although the STEL remains at 30 000 ppm.

Carbon dioxide build-up may also be a problem for sealed or air-tight office buildings. Chapter 10 outlines the causes and effects of sick building syndrome, and carbon dioxide is recognised as a major contributor. Ordinary outside air normally contains 300–350 ppm of carbon dioxide. However, with an indoor environment, human respiration, cooking and cigarette smoking increases that level. If the carbon dioxide concentration increases above 800 ppm, general complaints may arise from occupants.
The health effects from exposure to carbon dioxide include an increase in the breathing rate, excitation, headache and a feeling of ‘stiffness’. Obviously, as the concentration increases, the effect of oxygen deficiency becomes more noticeable. The worker may become cyanotic (have a blue tinge to the skin), their respiration increase rapidly and unconsciousness may follow.

**Ethane and ethylene**

Both ethane and ethylene are hydrocarbons, although ethane is an alkane (represented as \( \text{C}_n\text{H}_{2n+2} \)) and ethylene is an alkene (\( \text{C}_n\text{H}_{2n} \)). The characteristics of hydrocarbons are described later in this chapter. Their similarity lies in the common ethyl group (\( \text{CH}_2 \)).

Ethane is a colourless, odourless, flammable gas and is shipped in steel cylinders as a liquefied gas under its own vapour pressure. Typical uses include fuel for motors and as a refrigerant for extremely low temperature systems. It has the chemical formula \( \text{H}_3\text{–C–CH}_3 \). Ethane has a flammable range of 3.0–12.5 per cent, with a relative density of 1.0. According to dangerous goods classifications, ethane is a Class 2.1 flammable gas.

Ethylene (ethene) has the molecular size of the alkene series and the chemical formula \( \text{H}_2\text{–C–C–H}_2 \). Ethylene gas is used to ripen fruit, in order to make them suitable for market. While some fruits (e.g. apples, bananas, pears, peaches and plums) produce ethylene gas naturally, warehouses also make use of controlled atmospheres to reduce the ripening rate of the fruit to enable their sale during other periods of the year. Ethylene is also a starter of products such as:

- **Ethylene glycol (radiator inhibitor)** — the vapour has a TWA of 60 mg.m\(^{-3}\) and a STEL of 120 mg.m\(^{-3}\). Glycol ethers exist as a number of forms, such as monoethyl glycol ether (further details about the health effects are included later in this chapter).

- **Ethylene dibromide** — is a suspected human carcinogen, mutagen and teratogen. It can be absorbed through the skin, and no occupational exposure standard has been set in Australia. It has been used as a lead scavenger in leaded fuels (to retard lead deposition in the engine); a soil, grain and fruit fumigant; an intermediate in the synthesis of dyes and pharmaceuticals; and a solvent for resins, gums and waxes.

- **Ethylene dichloride (1,2 dichloroethane)** — has a TWA of 10 ppm and the liquid can irritate the skin. The vapour may irritate the eyes and mucous membranes, with repeated skin contact causing dermatitis. It has also been reported that exposure to high concentrations of vapour may produce dizziness and unconsciousness.

- **Ethylene oxide** — is a poisonous liquid or gas, which is highly flammable. It can irritate and damage the eyes, skin and lungs. It is also a suspected human carcinogen. Further discussion of ethylene oxide is included later in this chapter.

**Hydrogen and helium**

Hydrogen and helium are the two simplest elements and occupy the first and second places in the periodic table, respectively. Hydrogen (\( \text{H}_2 \)) was used for a limited period in the popular times of hot-air balloons. However, its flammable nature soon saw its demise after the catastrophe of the German Hindenberg airship, which burned at its mooring mast in 1937. Nowadays, helium is used in airships or
blimps that are used for television photography and advertising.

Hydrogen is both flammable and buoyant. It has a flammable range of 4–75 per cent and has a relative density of 0.1. Due to these characteristics and clean-burning, environmental scientists are looking towards hydrogen to replace the fossil-based energy used today. In its liquid form, it has been used as a fuel in space.

Helium (He) is an inert gas that is often used as a shielding gas.

**Methane**

Methane is classified as both a simple asphyxiant and as an explosive gas. It has the chemical formula CH₄ and is a by-product from the decomposition of organic matter. The explosive range of methane is 5–15 per cent, it has a relative density of 0.6, and is regularly found in the coalmines. The gas forms in pockets of the coal seam and escapes as the coal is mined. Methane is also released as the coal and coal-bearing rock are broken open. In years gone by, coalminers used canaries to indicate the presence of the gas. If the birds died, methane concentrations in the mine were considered to be at dangerous levels.

The magnitude of methane released from coal is dependent on the type of coal and how it is mined. For instance, lower quality coals (brown coal or lignite) have a lower methane content than higher quality coal (e.g. bituminous and anthracite coal). Underground coalmining typically releases more methane, since the coal is under pressure deep into the earth. Open-cut or surface mining generally has around 10 per cent of the methane content when compared to its underground counterparts.

Since methane has organic origins, it is also found in sewerage treatment plants, the rural industry (e.g. pig and cattle farming and dairy) from animal excrement and wetland rice fields.

**Neon**

The wonderful blaze of coloured lights used for advertising is due largely to neon (Ne), an inert and odourless gas that is lighter than air. The colours are formed when a high voltage is applied to the gas, causing its excitation and ionisation. As electrons return from the excited state to their normal orbit, they emit photons of light.

Typical applications of neon include fluorescent lamps, electric signs, an ingredient in antifog devices and lasers.

**Nitrogen**

Nitrogen is the main constituent of air, comprising around 79 per cent at normal temperature and pressure. Nitrogen can be used as an inert gas or as a shielding gas, in the process of manufacturing ammonia, to make fertilisers and to make explosives, medicines and dyes.

Other nitrogen products (oxides of nitrogen) include nitrogen dioxide (NO₂), dinitrogen oxide (N₂O₃) and nitrogen trioxide (NO₃). Laughing gas or nitrous oxide (N₂O) is another form of nitrogen. Further information about these gases is included later in the chapter.

**Propane and propylene**

These gases are hydrocarbons, with the similar propyl group. Propane has the molecular formula of C₃H₈, with the structure H₃C–CH₂–C–H₃. Most bottled gas and cigarette lighters contain propane. The flammable range of propane is 2.1–9.5 per cent. It has a relative density of 1.6. According to dangerous goods classifications, propane is a Class 2.1 flammable gas. Propylene (propene) has the formula CH₂=CH–CH₃, and can also be used as a fuel.
DETERMINING OXYGEN DISPLACEMENT FROM SIMPLE ASPHYXIANTS

As asphyxiant gases displace oxygen (and other gases) from an environment, it is important to realise that the reduction in concentration of individual gases occurs proportionally. Therefore, if 5 per cent (v/v) of propane is introduced into a space, the amount of air displaced is 5 per cent. However, the oxygen concentration is only reduced by approximately 21/100 of 5 per cent. This occurs since the propane will also displace other gases in the space, not just oxygen.

In order to determine the change in oxygen concentration that has resulted from the admission of an asphyxiant gas, we must consider:

- whether there will be ideal mixing (this concept is explained in Chapter 12)
- the concentration of asphyxiant gas added to the space (expressed as ppm or a percentage)
- the proportion of oxygen and other gases that usually exist in the ambient air (this may change depending upon the pressure within the space).

An example that illustrates how to determine the effect of adding asphyxiant gases into a space is shown in Case study 6.1.

CHEMICAL ASPHYXIANTS

This category of asphyxiants exhibits an effect not due to a reduction in oxygen concentration

Case study 6.1

Blackdamp, which consists of about 88 per cent nitrogen (N$_2$) and 12 per cent carbon dioxide (CO$_2$), is formed by the oxidation of the iron pyrites and calcite found in coal. When the concentration of blackdamp increases above 17.7 per cent, the miner’s safety lamp is often extinguished. Historically, this occurred when ventilation in the mine was inadequate, and would not be expected nowadays. So, if the miner’s safety lamp was extinguished, what was the concentration of oxygen in the air?

The answer to this is calculated by determining the proportional reduction of oxygen concentration that was caused by blackdamp. In other words, it is about 21 per cent of 17.7 per cent, or 3.8 per cent. Therefore, the oxygen concentration is about 21 per cent – 3.8 per cent, or 17.2 per cent.

To convert the percentage of N$_2$ and CO$_2$ to ppm in the environment, we must consider the concentration of N$_2$ and CO$_2$ formed from the blackdamp and add this to the natural concentrations of N$_2$ and CO$_2$. Therefore, for N$_2$ the concentration due to blackdamp is 88 per cent of 17.7 per cent, or about 15.8 per cent.

The total concentration of N$_2$ is 15.8 per cent (due to blackdamp) plus 79 per cent, or about 94.6 per cent. With CO$_2$, the concentration due to blackdamp is 12 per cent of 17.7 per cent, or about 2.1 per cent. The total gas concentration can be summed to around 100 per cent.
but from their interplay with the body’s homeostatic balance. Even at very low concentrations, chemical asphyxiants can affect the way the human body absorbs, transports and distributes oxygen throughout the body. It therefore follows that, while the concentration of oxygen in the working environment may be close to 21 per cent, damage to tissues can still occur. The national exposure standards for chemical asphyxiants are specified in the NOHSC’s *Exposure Standards for Atmospheric Contaminants in the Occupational Environment*. The major chemical asphyxiants of concern are:

- arsine
- carbon monoxide
- hydrogen cyanide
- hydrogen sulphide
- stibine.

**Arsine**

In Chapter 5, metallic arsenic was identified as a high-risk metal. Arsine (AsH₃) gas is formed when nascent hydrogen is produced in the presence of arsenic or arsenic-containing materials. The gas is colourless and flammable, and has a garlic-like odour. Arsine is used commercially in the manufacturer of semiconductors for the electronics industry. The symptoms of excessive exposure to arsine show themselves from the action on the blood. In mild cases the worker may have nausea, headache, shivering and abdominal pain. Jaundice may present after several days and the main organ that is affected is the kidney. The TWA for arsine is 0.05 ppm.

**Carbon monoxide**

Carbon monoxide (CO) is often known as the silent killer since it has no odour and the symptoms of exposure may be confused with general narcotic effects. It is produced by incomplete combustion of organic matter. Some sources include:

- diesel- or fuel-powered vehicles such as bobcats, forklifts, excavators and trucks
- fires
- gas or wood stoves
- heating processes — e.g. welding in a confined space (these spaces are defined under AS2865 and explained later in this chapter)
- cigarette smoke
- old model cars — with the development of catalytic converters, more carbon monoxide is oxidised and converted to CO₂ (a simple asphyxiant) before emission from the vehicle.

As a chemical asphyxiant, carbon monoxide elicits its effects through its affinity with haem atoms within haemoglobin, the oxygen-carrying component of red blood cells. In simple terms, haemoglobin prefers to bind with carbon monoxide rather than oxygen. This affinity is reported to be 250 times more for carbon monoxide than oxygen. In addition, the binding of carbon monoxide molecules with the haemoglobin prohibits the release of oxygen into the tissues, including vital organs such as the heart and brain. Therefore, in the presence of carbon monoxide, there are no mechanisms for oxygen transport and the tissues become deprived of oxygen (anoxia).

This combination of carbon monoxide and haemoglobin forms carboxyhaemoglobin (COHb). The build-up of carboxyhaemoglobin in the blood is dependent upon the concentration of the gas being inhaled and the duration of the exposure. However, another confounding factor in the risk of exposure is the long half-life of carboxyhaemoglobin in the blood (about five hours).

Death may occur when the carboxyhaemoglobin concentration in blood is 60–80 per cent. Since carbon monoxide is not a cumulative poison, any gas which has been taken up by the body will be released once
exposure is discontinued. A person suffering from carbon monoxide poisoning will show symptoms beginning with confusion, dizziness, loss of mental agility and lethargy. Table 6.3 illustrates the symptoms that are associated with different concentrations of carboxyhaemoglobin in the blood.

Table 6.3  Relationship between carboxyhaemoglobin concentration in blood and symptoms

<table>
<thead>
<tr>
<th>%COHb</th>
<th>Symptoms and outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>No symptoms. Heavy smokers can have as much as 9% COHb</td>
</tr>
<tr>
<td>15</td>
<td>Mild headache</td>
</tr>
<tr>
<td>25</td>
<td>Nausea and serious headache. Treatment with oxygen and/or fresh air will result in quick recovery</td>
</tr>
<tr>
<td>30</td>
<td>Symptoms intensify. Potential for long-term effects especially in the case of infants, children, the elderly, victims of heart disease and pregnant women</td>
</tr>
<tr>
<td>45</td>
<td>Unconsciousness</td>
</tr>
<tr>
<td>60%+</td>
<td>Death</td>
</tr>
</tbody>
</table>

Continued exposure to carbon monoxide can lead to headache, nausea and increased respiration as the body attempts to compensate for the lack of oxygen to the tissues. To summarise, the health effects from exposure to carbon monoxide include:

- a persistent or severe headache
- dizziness and blurred vision
- nausea
- fainting
- loss of muscle control
- fatigue
- rapid heartbeat or pulse or tightening of chest.

With exposure to carbon monoxide the skin will appear a bright cherry red colour from the carboxyhaemoglobin, compared with a blue tinge that is exhibited with simple asphyxiation.

The TWA for carbon monoxide is currently 30 ppm. A STEL has not been specified, since recommended guidelines to control short-term excursions above the TWA have been developed based on the toxicokinetic properties of carbon monoxide. Table 6.4 provides further guidance about the short-term effects of exposure to carbon monoxide.

**Hydrogen cyanide**

The toxicity of hydrogen cyanide (HCN) is related to its chemical composition. The cyanide ion as hydrogen cyanide or potassium cyanide (KCN) is more hazardous than the insoluble inorganic salts, as they only release the cyanide ion under certain conditions. It is likely to be found as a fumigant and in electroplating in the chemical industry, and may be produced when polyurethane foams are combusted.

Cyanide interferes with the oxidation of tissue but it does not interfere with the transport of oxygen, as is the case with carbon monoxide poisoning. In most cases of poisoning, the effects of excessive exposure occur so quickly that treatment must be given immediately. The main route of entry in the workplace is through inhalation, although it has been reported that ingestion of cyanide the size of a rice grain is sufficient to cause death.

Hydrogen cyanide causes deleterious effects by inhibiting the metal-containing enzymes (e.g. cytochromoxidase, which contains iron). This enzyme system assists in providing energy for respiration. When cell respiration ceases, it is no longer possible to maintain normal cellular functions. This may lead to the death of the cell.

The symptoms of cyanide poisoning will
depend upon the route of entry, duration of
exposure and concentration or dose. If the
route of entry were inhalation, the symptoms
would include:

- restlessness
- increased respiratory rate
- giddiness, headache and palpitations
- respiratory difficulty
- vomiting
- convulsions
- respiratory failure and unconsciousness.

If a worker is suspected of suffering from
cyanide poisoning, the treatment is aimed at
increasing the body’s ability to excrete cyanide
and bind cyanide in the blood. In the liver, the
enzyme rhodanese, together with sulphur,
transforms cyanide into thiocyanate, which is
then excreted in the urine. Since the cyanide
ion has a high affinity with trivalent iron (Fe$^{3+}$),
the blood haemoglobin is oxidised, leading to
the formation of methaemoglobin, which
binds cyanide ions.

For atmospheric sampling, the TWA for
airborne exposure to hydrogen cyanide is 10
ppm, expressed as the peak limitation. The
TWA for cyanides (as CN) is 5 mg.m$^{-3}$.
Further information about the symptoms and
outcomes of exposure to hydrogen cyanide are
listed in Table 6.5.

**Hydrogen sulphide**

In mines, hydrogen sulphide (H.S) is known as
stinkdamp. The obvious reason for this is that
it smells like rotting eggs. It is likely to be
found in the following areas where organic
matter may be rotting:
• sewers and sewerage sludge
• gasworks
• liquid manure
• sulphur hot springs
• oil refining
• mining.

Table 6.5 Symptoms and outcomes from exposure to hydrogen cyanide

<table>
<thead>
<tr>
<th>Concentration (mg.m⁻³)</th>
<th>Symptoms and outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>Immediately lethal</td>
</tr>
<tr>
<td>200</td>
<td>Lethal after 10 minutes</td>
</tr>
<tr>
<td>150</td>
<td>Lethal after 30 minutes</td>
</tr>
<tr>
<td>120–150</td>
<td>Fatal after 30–60 minutes</td>
</tr>
<tr>
<td>50–60</td>
<td>Endurable for 20–60 minutes</td>
</tr>
<tr>
<td></td>
<td>without effect</td>
</tr>
<tr>
<td>20–40</td>
<td>Light symptoms after several hours</td>
</tr>
</tbody>
</table>

Although the gas has an offensive odour it rapidly causes olfactory fatigue. The odour threshold is 0.0002 ppm. Hydrogen sulphide is a highly toxic and colourless gas. Even at low concentrations, its odour is very noticeable. However, with continued exposure and at high doses, it may deaden a person’s sense of smell, making the worker unaware of continued exposure. In other words, if the odour is no longer noticeable, it may not necessarily mean that exposure has stopped.

The symptoms from exposure include:

- irritation of the eyes, nose and throat (low levels of exposure); which may include blurred vision and photophobia
- headache, dizziness, nausea, vomiting, cough and difficulty breathing (moderate exposures)
- shock, convulsions, coma and death (high-level exposures).

In most cases, removing the worker from the source of exposure and initiating fresh air and oxygen therapy can treat exposure to hydrogen sulphide. After a single, small exposure with quick recovery, no delayed or long-term effects are likely to occur. If a serious exposure that caused coma or convulsions was experienced, damage may have been done to the brain and heart. The mechanism of effect for hydrogen sulphide occurs through its effect on the medulla (in the brain). This affects the respiratory centre and causes a paralytic effect.

In Australia, the TWA for hydrogen sulphide is 10 ppm. The STEL is 15 ppm.

**Stibine**

Stibine (hydrogen antimonide or antimony trihydride) is formed in a similar way to arsine, although antimony is the contact metal. It is highly toxic and colourless, and has an unpleasant smell (like hydrogen sulphide). The TWA is 0.1 ppm.

**Case study 6.2**

An occupational hygienist monitors a workplace environment and finds a concentration of 20 ppm of hydrogen cyanide. Hydrogen cyanide is a chemical asphyxiant. While this measured concentration of hydrogen cyanide is double the NOHSC TWA, it will not significantly affect the oxygen concentration of the environment. Hence, chemical asphyxiants must be specifically monitored for the substance. Measurement of oxygen concentration will not allow accurate estimation of the risk of chemical asphyxiants.
IRRITANT GASES

Irritant gases are not respirable except at very low concentrations. Their action on the respiratory tract depends on their solubility. For instance, soluble gases such as ammonia and chlorine dissolve out of the inhaled air in the upper respiratory tract and show lesser effects on the lung. Insoluble gases such as nitrogen dioxide penetrate the lungs, causing serious damage.

The symptoms from exposure to irritant gases include tearing of the eye, respiratory irritation, coughing, asthma, cloudy vision at high concentration or other problems with vision, and an acidic taste. In the workplace, the major irritant gases of concern are:

- ammonia
- chlorine
- ethylene oxide
- fluorine
- formaldehyde
- glutaraldehyde
- nitrous gases
- ozone
- phosgene
- sulphur dioxide.

Ammonia

Ammonia (NH₃) is a colourless gas with a very strong odour. It is also water-soluble and shows its effects through its caustic action. However, when ammonia dissolves in water, it changes to the ammonium ion (NH₄⁺). It is used as:

- a refrigerant
- an ingredient in the manufacture of explosives.
- an ingredient in the manufacture of fertiliser production
- a component to manufacture synthetic fibres and plastics

In addition to manufacturing processes that use ammonia as a starting component or intermediate, workers may be at risk where ammonia is stored (from pipelines and during transportation). Rural workers who apply ammonia-based fertilisers to pasture may be exposed. Decaying manure (especially from chickens) also releases ammonia.

Most exposure to ammonia occurs through inhalation. Inhalation may cause a chemical bronchitis with pulmonary oedema and a cough with a frothy, sometimes blood-stained sputum. If splashed on the skin ammonia will cause a burn, and if exposed to high concentrations this may cause systemic effects on the body. The vapour will cause irritation of the conjunctiva and the more serious effect of ulceration of the cornea may occur if splashed on the eye. Scar tissue and perhaps blindness may also result if ammonia is splashed on the eye.

The NOHSC TWA for ammonia is 25 ppm and the STEL is 35 ppm. Exposure to levels of ammonia around 50 ppm can cause temporary eye and throat irritation. If a worker is exposed to 500 ppm for 30 minutes, the person is likely to suffer from a sore nose and throat and their rate of respiration will increase.

Chlorine

Chlorine (Cl₂) is an oxidising agent and has specific use as a bleach and disinfectant. Typical industrial applications include bleaching of paper, treatment of water supplies, pools and sewage. It is also used to disinfect equipment and utensils in beverage and food processing plants, and as an intermediate in the manufacture of a number of organic products such as antifreeze, rubber, cleaning agents and pharmaceuticals.

The gas has a greenish-yellow colour and a strong odour which is extremely irritating. The
odour threshold for Cl₂ is 0.31 ppm. Exposure leads to a feeling of choking and causes a burning pain, excessive salivation and tearing of the eye. The TWA for chlorine is 1 ppm, expressed as the peak limitation.

A summary of the health effects from exposure to chlorine include:

- **chest pain, vomiting, toxic pneumonitis, pulmonary oedema and death** (acute exposure at levels above 30 ppm)
- **irritation to the eyes, upper respiratory tract and lungs** (acute exposure less than 3 ppm)
- **respiratory complaints, corrosion of the teeth, inflammation of the mucous membranes of the nose** (chronic exposure at 5 ppm)
- **burns to the skin from liquid exposure.**

**Ethylene oxide**

Ethylene oxide is used as the starting agent in the manufacture of ethylene glycol, the radiator inhibitor used in motor vehicles. It is also a fumigant and is used as a sterilising agent that is usually mixed with carbon dioxide. Inhalatory exposure irritates the mucous membranes and liquid ethylene oxide may produce severe chemical burns. The TWA is 1 ppm. Ethylene oxide is a Category 2 carcinogen, which means it is probably carcinogenic in humans. It should be treated as though it is carcinogenic and exposure avoided where possible.

It has been reported that skin exposure to ethylene oxide can cause burns similar to frostbite. Ethylene oxide has a flammable range of 3.0–100 per cent, and can explode if mixed with air and exposed to fire or sparks. Its relative density is 1.5.

Exposure to ethylene oxide typically occurs in:

- hospitals
- workplaces that manufacture hospital and medical supplies
- museums
- libraries and archives
- food-processing industries
- sterilisation training institutions
- animal laboratories (which use ethylene oxide as a sterilising or fumigation agent).

**Fluorine**

In the free state, fluorine (F) is a green-yellow corrosive gas with a low odour threshold. It is also the most electronegative and reactive of all elements. When combined with metals, glass, ceramics, carbon or water, a bright flame is emitted. It is often found combined with other elements or compounds, such as with calcium to form fluorspar (calcium fluoride) or in the production of cryolite (sodium aluminium fluoride). As early as 1529, Georgius Agricola described the use of fluorspar as a flux, and in 1670 Schwandhard learnt that glass was etched when exposed to fluorspar treated with acid. When combined with hydrogen, a powerful acid called hydrofluoric acid is formed.

Fluorine and its compounds are used for:

- producing uranium for nuclear energy applications (from hexafluoride)
- making more than a hundred commercial fluorochemicals (e.g. high-temperature plastics and hydrofluoric acid to etch the glass of light bulbs)
- airconditioning and refrigeration gases.

In some parts of Australia, soluble fluorine is added to water supplies to prevent cavities of the teeth. However, if the concentration rises above 2 ppm, it may cause mottled enamel in
the teeth of children who consume water while developing permanent teeth. Since elemental fluorine and the fluoride ion are extremely toxic, a low occupational exposure has been set by the NOHSC. For fluorine, the TWA is 1 ppm and the STEL is 2 ppm. Although even at these concentrations, the pungent odour may be detectable — the odour threshold for fluorine can be as low as 20 parts per billion!

**Formaldehyde and glutaraldehyde**

These substances are both aldehydes. Both formaldehyde and glutaraldehyde are sensitisers. This means they can cause an immune response in some people. Once sensitisation has occurred, exposure can manifest itself as a skin rash, inflammation or asthma-like response. It should also be noted that although low occupational exposure standards have been set for these substances, they might still not protect all workers. Workers who are already sensitised to formaldehyde or glutaraldehyde should not be exposed further.

**Formaldehyde**

Formaldehyde was first discovered by August Wilhem von Hofman in 1867 but pure formaldehyde was not isolated until 1892 by Friedrich August Kekule von Stradonitz. It has the chemical formula HCHO. Formaldehyde can be manufactured by the oxidation of methanol with air, using a metal catalyst around 400–650°C.

Formaldehyde is a colourless gas with a strong odour. Since it is very polar, formaldehyde is soluble in both water and ethanol. Formalin is formed by mixing formaldehyde with water to form a 37 per cent solution. Formaldehyde is used for:

- **fixing and preserving biological specimens** (as formalin), in laboratories and mortuaries
- **a component of resins and glues** (as urea-formaldehyde) for particle board, carpets, laminates and MDF, which can contain between two and four times the amount of urea-formaldehyde than is found in standard particle board
- **a fire-retardant and stiffener in fabric**
- **making paper products, cosmetics, deodorants, shampoos, fabric dyes, permanent-press fabrics, inks and disinfectants**
- **enhancing wrinkle-resistance and water-repellancy in cotton and cotton blend fabrics**
- **enhancing the water-repellency of packaging paper**, by treating the wood pulp with urea-formaldehyde resin.

There are several types of formaldehyde resin mixtures, mainly phenol-formaldehyde, melamine-formaldehyde and urea-formaldehyde. Because of its water-solubility, urea-formaldehyde is the substance that contributes the most to indoor air pollution. The release of formaldehyde from building materials in an indoor environment is known as off-gassing. The rate of gas release depends on the air temperature and humidity. For instance, an increase in temperature of 5–6°C can double the concentration of gas. If the relative humidity changes from 30 per cent to 70 per cent, this may result in a 40 per cent increase in formaldehyde concentration. However, where both the temperature and humidity are increased, the resulting formaldehyde level can increase to as much as five times its original level.

Formaldehyde is also a combustion product that is emitted from cigarette and wood smoke, natural gas, kerosene and exhaust from vehicles. The symptoms of low-level exposure to formaldehyde include irritation of the eyes, nose and throat, coughing, dermatitis and sleeping difficulties.
If acute exposure occurs, the symptoms may extend to:

- headache and fatigue
- breathing difficulties and sinus irritation
- chest pain and asthma attacks
- nausea and vomiting
- nose bleeds
- decreased lung capacity
- abdominal pain, anxiety and diarrhoea.

If the exposure to formaldehyde is relatively short term, the symptoms disappear once exposure ceases. However, exposure over the longer term may be more deleterious.

Formaldehyde is normally present at low levels in the atmosphere, usually less than 0.06 ppm. However, above 0.1 ppm, workers may show symptoms of exposure. Some research indicates that formaldehyde is carcinogenic. The NOHSC has classified formaldehyde as a Category 2 carcinogen with a TWA of 1 ppm and STEL of 2 ppm.

Glutaraldehyde

Glutaraldehyde is used:

- as a biocidal additive in conveyor chain lubricants
- in sanitary fluids and added to toilet systems
- as a disinfectant of endoscopes and other invasive tools used in surgery
- in X-ray film processing
- to disinfect air ducts.

The typical route of entry is through inhalation or skin absorption. Biocides are usually made from an aqueous glutaraldehyde solution up to 50 per cent (w/w) or diluted to 0.5–10 per cent. The TWA of glutaraldehyde is 0.1 ppm, with a peak limitation specified. Typical symptoms of exposure to glutaraldehyde include irritation of the nose and throat (at concentrations generally less than 0.2 ppm) and contact dermatitis.

Nitrous gases

The irritant nitrous gases are nitrogen dioxide (NO₂) and dinitrogen tetroxide (N₂O₄). The other oxides of nitrogen are non-toxic.

Nitrous gases may be produced during oxyacetylene, carbon-arc or electric-arc welding and in mining when dynamite burns quietly instead of exploding. Nitrous gases have a reddish-brown colour. The TWA for nitrogen dioxide is 3 ppm and the STEL is 5 ppm.

Exposure to nitrogen dioxide can affect the body in a number of ways. For instance, the reaction of NO₂ and water in the aqueous environment of the lung can form acids, which damage lung epithelium and may result in pulmonary oedema and pneumonia. Other oxides of nitrogen can impact on the body’s defence systems by destroying macrophages and compromising local immunity.

Ozone

Ozone is formed through the oxidisation of oxygen (O₂) to O₃. This gas has a distinctive smell and is irritating to the respiratory centre. Around 90 per cent of inhaled ozone is never exhaled. It can also affect the normal functioning of lungs and reduce the ability to perform physical exercise. Symptoms from exposure include a cough, chest pain and throat irritation. Ozone may increase the susceptibility of the lungs to infections, allergens and other pollutants. Some studies have indicated that ozone damages lung tissue.

Since ozone is formed through an oxidisation process it requires a high-energy source to produce it. Workplaces where ozone is found include those with older-style photocopiers and electric arc-welding.
machines. Ozone is a sensitiser and has a TWA of 0.1 ppm. This is expressed as the peak limitation.

Ozone is present in the upper layer of the earth’s atmosphere, the stratosphere. Much media attention has been given to the ozone layer in recent times, due to a decrease in the amount of ozone and the so-called greenhouse effect. While scientific debate continues about the extent of damage to the earth, a general consensus prevails that the continued destruction of the ozone layer has resulted in an increase in the earth’s temperature, exposure to ultraviolet radiation (Chapter 9 discusses the health effects from exposure to UV radiation) and changes in weather patterns.

**Phosgene**

Phosgene is much more toxic than chlorine. At room temperature it exists as a colourless gas that has a suffocating odour at high concentrations. At low concentrations, its odour resembles newly mowed hay. It may be found:

- **where chlorinated hydrocarbons have been heated** — for instance, where degreasing agents such as carbon tetrachloride have been used adjacent to welding or cutting processes and the vapour is unconfined
- **in the manufacture of chemicals.**

Exposure to low concentrations may cause slight irritation of the eyes and upper respiratory tract. The TWA for phosgene has been changed in recent years to 0.02 ppm, with a STEL of 0.06 ppm.

**Sulphur dioxide**

Sulphur dioxide (SO₂) has been used industrially in magnesium foundries and was previously used as a preservative in food and wine. It is highly irritating to the mucous membranes of the eye and respiratory tract. Serious health effects are rarely seen due to the extreme irritant nature of the gas, which precipitates the movement of the worker away from the contaminated area. The TWA for sulphur dioxide is 2 ppm and the STEL is 5 ppm.

While sulphur dioxide is colourless, it does have a pungent odour that is detected around 0.5–0.8 ppm. It is also highly soluble in water. This results in the formation of sulphurous acid, which is easily converted to sulphuric acid (H₂SO₄). Sulphuric acid is a major acidic component of acid rain. On a worldwide basis, oxides of sulphur are thought to be one of the major pollution problems. With the continual combustion of fossil fuels (coal and oil) in power stations and refineries, its emission is escalating. Diesel emissions and volcanic eruptions are also sources of sulphur dioxide. Table 6.6 shows the effects of exposure to sulphur dioxide at various concentrations.

| Table 6.6 Symptoms from exposure to sulphur dioxide |
|-----------------|---------------------------------|
| **Concentration** | **Symptoms and outcomes** |
| (ppm) | |
| 400 | Lung oedema, bronchial inflammation |
| 20 | Eye irritation, coughing |
| 0.5 | Odour threshold |

The mechanism of effect with exposure to sulphur dioxide is believed to be similar to that of exposure to oxides of nitrogen. As the sulphur dioxide dissolves in the mucous lining of the respiratory system, its viscosity increases. This causes the airway resistance and mucociliary clearance to decrease. In the bronchioles, small-sized acid aerosols may produce an irritant effect which, with repeated exposure, may lead to bronchitis.
SOLVENTS

Solvent is a broad term given to a number of chemical groups with a similar characteristic of dissolving other substances. They are used to extract oils and fats and in paints, varnishes, polishes, cleaning materials and fabrics. Solvents may also be used for extracting medicinal materials from bones, seeds and nuts, and for degreasing. Chemical reactions may be better facilitated by the addition of solvents that act to dissolve the specific chemical reagents. The toxicity and hence hazard is affected by the group of solvent.

The nine solvent groups are:

- hydrocarbons
- halogenated hydrocarbons
- alcohols
- ethers
- glycol derivatives
- esters
- ketones
- aldehydes and ketals
- miscellaneous solvents.

This section of the chapter broadly describes the characteristics of the nine solvent groups before moving on to discuss the hazardous nature of some chemical contaminants of occupational hygiene significance.

Health effects of exposure to organic solvents

There are many thousands of organic compounds that are used in industry and many more hundreds introduced each year. The effects to health upon exposure to these substances can vary quite significantly, depending on several factors. Organic solvents may be either fat-soluble or water-soluble. They can be biotransformed in or move throughout the body in their original forms. Their solubility determines the distribution in the body — for instance, fat-soluble solvents tend to accumulate in the nervous system. Water-soluble solvents have the potential to move throughout most other parts of the body. As already mentioned, the solubility of the solvent will also affect the route of entry. While both fat- and water-soluble solvents can enter the lungs through inhalation, only fat-soluble solvents can be absorbed through the skin and enter the body through this mechanism.

Some solvents are biotransformed once absorbed into the body. This is discussed in Chapter 1. Biotransformation refers to the reaction of converting a substance to another, through complex interactions. The by-products of biotransformation are known as metabolites and can show themselves as indicators of exposure. Biological monitoring can be used to determine workers’ actual exposure to such substances and may indeed include estimations of the concentration of the unchanged substance or its metabolite.

Hydrocarbons

Hydrocarbons are substances that contain hydrogen (H) and carbon (C). They may also have a functional group attached (see Table 6.7) which is responsible for most of the chemical behaviour of the parent molecule.

<table>
<thead>
<tr>
<th>Functional group</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>−NH₂</td>
<td>Amino</td>
</tr>
<tr>
<td>−F</td>
<td>Fluoro</td>
</tr>
<tr>
<td>−Cl</td>
<td>Chloro</td>
</tr>
<tr>
<td>−Br</td>
<td>Bromo</td>
</tr>
<tr>
<td>−I</td>
<td>Iodo</td>
</tr>
<tr>
<td>−NO₂</td>
<td>Nitro</td>
</tr>
<tr>
<td>−CH=CH₂</td>
<td>Vinyl</td>
</tr>
<tr>
<td>C₆H₅</td>
<td>Phenyl</td>
</tr>
</tbody>
</table>

Hydrocarbon solvents are obtained as a product or by-product of petroleum or coal...
refining, and all the members of this group are flammable. Aliphatic hydrocarbons — including alkanes, cycloalkanes, alkenes and alkynes — are straight or branched chains of carbon, saturated with hydrogen; while aromatic (one hydrogen atom per carbon atom) hydrocarbons contain a six-ring structure.

Alkanes have the general chemical formula $\text{C}_n\text{H}_{2n+2}$. Each carbon atom is joined by only a single bond. The simplest member of the alkane family is methane. Naming of alkanes (this is known as nomenclature) is quite easy. Except for the first four members, the number of carbon atoms in each alkane is reflected in the Greek prefix. When one or more hydrogen atoms are replaced by other groups, the name of the substance must indicate the location of the carbon atoms where replacements are made.

For the first four alkanes, the prefixes used reflect the alkyl groups. These are:

- methyl ($\text{CH}_3$)
- ethyl ($\text{C}_2\text{H}_5$)
- propyl ($\text{C}_3\text{H}_7$)
- butyl ($\text{C}_4\text{H}_9$).

The cycloalkane family has its carbon atoms joined in rings, with the general formula $\text{C}_n\text{H}_{2n}$. Some examples of these substances are cyclobutane ($\text{C}_4\text{H}_8$) and cyclohexane ($\text{C}_6\text{H}_{12}$).

Alkenes ($\text{C}_n\text{H}_{2n}$) are hydrocarbons that contain at least one carbon–carbon double bond. They are named in a similar manner to the alkanes, although the numbering begins at the double-bond location. Some examples of alkenes include ethylene ($\text{C}_2\text{H}_4$) and propylene ($\text{C}_3\text{H}_6$). Due to the geometric arrangement of the carbon atoms of alkenes, there are often two isomers of alkenes. These isomers typically have different physical and chemical properties.

Alkynes ($\text{C}_n\text{H}_{2n-2}$) contain at least one carbon–carbon triple bond. The name of the substance is given by considering the number of carbon atoms in the longest chain. The simplest alkyne is acetylene ($\text{C}_2\text{H}_2$).

Aromatic hydrocarbons all have the common characteristic of a ring that contains six carbon atoms. The simplest aromatic hydrocarbon is benzene ($\text{C}_6\text{H}_6$), although carbon atoms can be substituted to form other aromatic compounds. For instance, chlorobenzene substitutes one carbon atom for a chlorine atom, ethylbenzene substitutes an ethyl group for the carbon atom, and nitrobenzene substitutes a NO$_2$ group for the carbon. Aromatic hydrocarbons can also be fused together to form many types of polycyclic hydrocarbons, for instance:

- naphthalene
- benz (a) anthracene
- benzo (a) pyrene.

With all of the polycyclic aromatic hydrocarbons, the greater the number of rings, the more toxic and potentially carcinogenic the substance. For instance, as described in Chapter 1, scrotal cancer in chimney sweeps has been recognised as being caused by exposure to large quantities of soot and tar which contain many types of carcinogens, mostly polycyclic aromatic hydrocarbons.

Aromatic hydrocarbons differ vastly in chemical and physical characteristics from aliphatic hydrocarbons, with the aromatics being far more toxic than the aliphatics. The aromatic members are all potent narcotic agents and overexposure can quickly lead to loss of muscular coordination, collapse and unconsciousness.

**Halogenated hydrocarbons**

The term halogen is applied to five elements — fluorine, chlorine, bromine, iodine and astatine. For industrial purposes, the chlorinated compounds are the most important members of this group with chlorobenzene being a well-known solvent. It has an acute action on the central nervous
system, although there are believed to be no chronic effects. Exposure to some chlorinated hydrocarbons can cause an angry rash on the skin, known as chloracne. This has been well documented in the motor repair industry where, until recently, chlorinated solvents were used widely as degreasers.

**Alcohols**

Alcohols have a chemical structure –OH. This group includes monohydric and polyhydric solvents. Polyhydric alcohols have only recently become popular as an industrial solvent. Methyl alcohol, n-propyl alcohol, n-butyl alcohol and ethyl alcohol are most commonly used as solvents in the preparation of alkyd resins, new synthetic fibres and synthetic polymer rubber. Some common alcohols include:

- methanol (methyl alcohol)
- ethanol (ethyl alcohol)
- 2-propanol (isopropyl alcohol)
- phenol
- ethylene glycol.

**Ethers**

Ethers have the chemical formula R–O–R, where R is the functional group. They are characterised by a greater volatility (and hence high flammability) and lower solubility in water than other chemical compounds. However, they do have a high solvent power for oils, fats and greases (which makes them ideal for use as solvent). Ethers are very dangerous substances to handle. They are highly narcotic and large doses may lead to death.

**Glycol derivatives**

The best-known solvents of this classification are ethylene glycol, monomethyl ether and ethylene glycol monoethyl ether. Each have a different toxic effect on the nervous system of the body and the blood. These solvents are used in hydraulic brake fluids, nitrocellulose and synthetic resins, printing inks, writing inks, spirit-diluting fluids and dye solutions. They may also find use as rust removers, degreasing agents and dry-cleaning soaps, due to their penetrating qualities.

**Esters**

Generally speaking, esters do not constitute a serious hazard to workers’ health. They are widely used as solvents for surface coatings although excessive exposure may lead to irritation of the nose, eyes and upper respiratory tract. Esters have the chemical structure R’COOR, where R is a functional group and R’ is a hydrogen atom or functional group.

**Ketones**

Ketones contain the double-bonded carbonyl group (C=O) with two groups on the carbon. With the growth of acetate rayon and vinyl resin coatings, ketones have become an increasingly important solvent. The most common solvents of this type are acetone and methyl ethyl ketone (MEK).

**Aldehydes and ketals**

These are volatile, flammable liquids. Aldehydes, in particular, have strong irritant effects on the eyes, skin and respiratory system. Some examples of aldehydes include formaldehyde and glutaraldehyde.

**Miscellaneous solvents**

This group includes:

- nitroparaffin
- certain solvents of organic origin
- carbon disulphide
- acids and amines (also included in this group for convenience).
Carbon disulphide is one of the most dangerous solvents used in industry with a high flammability and low ignition temperature of around 100°C. It acts on the peripheral and central nervous systems and has been reported to cause heart irregularities. It has a TWA of 10 ppm.

**Benzene**

Historically, the use of benzene as a solvent in industry has been extensive. It was used as a solvent in the manufacture of rubber or plastic shoes and in photogravure printing. It also may still be found in fuel. Benzene is absorbed through the lung and the skin, since it is fat-soluble. Due to its lipophilic characteristic, it accumulates and stores in the fatty tissue. While a large amount of benzene is exhaled unchanged, between 15 per cent and 60 per cent of the absorbed substance is biotransformed in a complex reaction. Its biological half-life is around twelve hours.

Exposure to benzene is not commonly reported to have caused acute poisoning — although accidental exposure may lead to very high concentrations of the vapour and present as symptoms of euphoria, headache and vomiting. The more sinister, adverse health effect is associated with long-term exposure to the solvent. Benzene has its main effect on the bone marrow and is linked with the development of acute leukaemia. If workers are to be exposed to benzene, they should be assessed by an occupational physician to determine their occupational history and medical history and a blood sample for haematological profile should be collected. In Australia, the occupational exposure standard (TWA) for benzene has recently been reduced from 5 ppm to 1 ppm and it is classified as a Category 1 carcinogen.

**Toluene**

Toluene is a commonly used hydrocarbon solvent which is found in resins, glues and paints. It is absorbed through the lungs and the
skin, although it is rapidly excreted once exposure has ceased. Biological monitoring for its metabolite, hippuric acid, can be performed to detect exposure to toluene, since about 90 per cent of the inhaled toluene is biotransformed to this substance. Excessive exposure to toluene vapours can give a feeling of euphoria and causes narcosis. The TWA for toluene has recently been halved from 100 ppm to 50 ppm. The STEL remains at 150 ppm. Above about 1000 ppm toluene causes vertigo and an intense headache. High concentrations are hallucinogenic.

Toluene is not reported to affect the peripheral nervous system, although excessive exposure can cause death (such as in glue sniffers) where ventricular arrhythmia occurs due to sensitisation of the myocardium.

**Xylene**

Xylene is used less commonly than toluene, as a thinner for paints and varnishes. Between 60 per cent and 65 per cent of inhaled xylene is absorbed — and it can enter the body through both inhalation and skin absorption. The route of biotransformation is similar to toluene, although it forms methyhippuric acid instead of hippuric acid. Xylene consists of several isomers, the most common being o–, p– and m–. The TWA for xylene is 80 ppm and the STEL is 150 ppm.

**Styrene**

Styrene is a very reactive organic solvent which is used primarily in the manufacture of polystyrene and synthetic rubbers and is a component of the resin used in fibreglass. It has a pungent odour and exposure to styrene produces feelings of vague ill health at low concentrations, although its irritant effects may affect the eyes, nose, upper respiratory tract and skin. In Australia, the TWA for styrene monomer is 50 ppm and the STEL is 100 ppm.

**Carbon tetrachloride**

This solvent is used in the production of freons but has also been used historically as a solvent, fumigant, in fire-extinguishers and as a dry-cleaning agent. Its high toxicity has seen it replaced by other compounds, where possible. Carbon tetrachloride had its occupational exposure standard in Australia reduced from 5 ppm to 0.1 ppm in 1996 and is classified as a Category 2 carcinogen. It also may be absorbed through the skin.

Adverse health effects of exposure are related to its lipid affiliation, as showing damage to the liver or renal symptoms. Initially, exposed persons may complain of persistent headache, nausea and vomiting. If damage to the hepatic system occurs, jaundice and alterations in liver function may be noted.

**1,1,1-Trichloroethane (methyl chloroform)**

Trichloroethane is one of the most widely used solvents, particularly in the degreasing of metals. It is rapidly absorbed through the lung and may also be absorbed through the skin. Exposure may cause irritant dermatitis and conjunctivitis if splashed in the eye. The usual narcotic effects similar to exposure to other solvents will also occur at high concentrations. The TWA is 125 ppm.

**Trichloroethylene**

Trichloroethylene was historically used as a dry-cleaning agent and refrigerant but has generally been replaced by other solvents for this purpose. It is still used as a degreasing agent and may also be used as an anaesthetic.

This solvent has been reported as one of the solvents most likely to cause sudden death syndrome, where death occurs in a young person who has been heavily exposed to the solvent following some exertion. The TWA for
trichloroethylene is 50 ppm and the STEL is 200 ppm.

**Tetrachloroethylene (perchlorethylene)**

Tetrachloroethylene has replaced trichloroethylene to a large extent as a dry-cleaning fluid and degreasing agent. The vapour may be absorbed through the skin and lungs and is stored in fatty tissues. The TWA for perchlorethylene is 50 ppm and the STEL is 150 ppm.

**Methylene chloride (dichloromethane)**

Methylene chloride is used in the manufacture of cellulose acetate film and is a component of some paint strippers. It is absorbed through the lungs and is primarily metabolised to carbon dioxide; however, around one-third of the absorbed substance is converted to carbon monoxide.

Waldron (1990) reports that an eight-hour exposure to about 150 ppm of methylene chloride will produce an equivalent amount of carboxyhaemoglobin as exposure to 35 ppm of carbon monoxide for the same time. The TWA for methylene chloride is 50 ppm. It has been classified as a Category 2 carcinogen, meaning it is suspected of having carcinogenic potential. Current epidemiological or animal studies have indicated that methylene chloride may cause cancer in humans.

**Carbon disulphide**

Carbon disulphide is a particularly toxic substance whose use is being steadily restricted. It is a multi-system poison; the most important effects are neurological and cardiovascular. It also has shown to be a skin irritant and may induce gastrointestinal disorders. Both the central and peripheral nervous systems can be affected by exposure to carbon disulphide. In high concentrations a toxic organic psychosis may be induced. The symptoms include severe irritability, uncontrolled anger, insomnia and loss of memory.

In the peripheral nervous system, carbon disulphide causes the slowing of nerve conduction velocities (an early indication of axonal damage) although the conduction velocities return to normal if exposure is ceased. Long-term exposure to carbon disulphide is reported to greatly increase the prevalence of ischaemic heart disease. The TWA for carbon disulphide is 10 ppm.

**Other Chemical Contaminants of Occupational Hygiene Significance**

**Acid mists**

The acidity of a chemical substance refers to its hydrogen potential or pH. If a contaminant has a low pH (between 0 and 7), it is acidic. If the pH ranges between 8 and 14, it is alkaline or basic. Neutral substances have a pH of 7. In the workplace, the most common health effects from exposure to acids and alkalis relate to their caustic nature. The skin is therefore the main target. Exposure may result in severe burns. Some particularly caustic acids such as hydrofluoric acid (HF) continue to burn through the skin and tissues until they reach the bone. Other examples of acids are hydrochloric acid (HCl) and sulphuric acid (H₂SO₄). While skin absorption is of major concern, acids can also be inhaled as mist.

Mists are suspended liquid droplets that are generated by condensation of vapour back to the liquid state or by breaking up through splashing. Acid baths used for pickling metals are typical sources of exposure. Ulceration of the hands, especially around the fingernails,
has also been noted in people detailing cars using a dilute solution containing hydrofluoric acid. The occupational exposure standards for atmospheric exposure are 5 ppm for hydrochloric acid (hydrogen chloride) and 3 ppm for hydrofluoric acid (hydrogen fluoride). These are expressed as peak limitations. For sulphuric acid (hydrogen sulphide), the TWA is 10 ppm and the STEL is 15 ppm.

**Coal tar pitch (creosote)**

Coal tar pitch contains volatile organic compounds that can be emitted during road repair operations involving hot asphalt. They actually consist of a mixture of hydrocarbons that are a Category 1 carcinogen. It has been estimated (NOHSC 1996) that creosote is a complex mixture of 1000 compounds. The health effects from exposure include:

- photosensitivity
- irritation of the skin (resulting in red ulcers or papules)
- nausea and vomiting
- diarrhoea, anorexia and difficulty swallowing
- headache, fainting, vertigo and mental disturbances.

The TWA for coal tar pitch (measured as the benzene soluble fraction) is 0.2 mg.m$^{-3}$.

**Drugs and poisons**

In Australia, drugs and poisons are defined under the Australian Dangerous Goods Code (ADG Code) as Class 6 substances. Pharmaceutical drugs are then further classified according to the Drug and Poisons schedule. Occupational exposure to pharmaceutical drugs is of concern in their manufacture, where controls can be inadequate to prevent workers from being exposed to the ingredients and their by-products. Other poisons include those used in the rural industry, such as:

- herbicides (e.g. amitrole, ammonium sulphamate, atrazine, borates, bromacil, 2-4 D, diuron, paraquat)
- rodenticide (e.g. ANTU)
- fungicides (e.g. benomyl, captan, ferbam)
- fertiliser (e.g. calcium cyanimide)
- pesticides (e.g. carbaryl, chloropyrifos, strychnine)
- insecticide (e.g. carbofuran, dieldrin, heptachlor, kepone, pyrethrum).

Monitoring for drugs and poisons is not easy. Since most adverse exposure occurs through ingestion or absorption (and not inhalation), it is best to conduct biological monitoring of the body or its metabolites.

Typically, the cholinesterase level in the blood is measured from blood tests. Since most poisons inhibit the nervous system by inhibiting the release of cholinesterase, exposure can cause respiratory failure.

**Ethylene glycol**

Ethylene glycol is a colourless, sweet-tasting liquid that is used as antifreeze in vehicles and to manufacture polyester fibres and film. Historically, it was used in the manufacture of explosives during World War I (substituting glycerol). Some other areas of application of ethylene glycol include:

- as a heat-transfer fluid
- in aircraft and runway de-icing mixtures
- to improve flexibility and drying time of oil-based paints
- as a dehydrating agent for natural gas
- in motor-oil additives
- as an additive in inks, pesticides, wood stains and glues.

Exposure to ethylene glycol via ingestion can lead to stimulation of the central nervous
system. This is followed by depression, and kidney damage and death may also result.

Ethylene glycol is also used to make glycol ethers. Glycol ethers (e.g. monobutyl glycol ether) are suspected of increasing the risk of miscarriage for pregnant women working in the manufacturing of semiconductor chips.

**Isocyanates**

Isocyanates are a group of chemicals that are known respiratory and skin sensitisers. They are used in the manufacture of polyurethane foams and are a component of some 2-pack paints and varnishes. The three main isocyanates that are found in the workplace setting are:

- MDI (methylene bisphenyl isocyanate)
- TDI (toluene 2,4 diisocyanate)
- HMDI (hexamethylene diisocyanate).

If the eyes are exposed to isocyanates, this may lead to severe chemical conjunctivitis. Sensitised workers may show symptoms after exposure to even tiny amounts of isocyanates. Additional health effects include damage to the liver and kidney. A chronic effect is interstitial pulmonary fibrosis.

The occupational exposure standards for MDI, TDI and HMDI are 0.02 mg.m\(^{-3}\) (TWA) and 0.07 mg.m\(^{-3}\) (STEL). Health surveillance of workers exposed to isocyanates should include administration of a standardised respiratory questionnaire, physical examination of the skin for occupational dermatitis, lung function test and the collection of medical history information.

**Methyl bromide**

Methyl bromide is used as a fumigant and rodenticide. Exposure to workers is usually limited to those who come into contact with fumigation of timber items or may be unloading the items after importing. The shipment is usually treated by covering with impervious sheeting and pumping the methyl bromide through the products. Otherwise, some containers are treated with canisters containing methyl bromide. The TWA is 5 ppm.

**Methyl methacrylate and ethyl methacrylate**

Both of these chemicals are hydrocarbons and are used in the manufacture of prosthetics and dentures. Methyl methacrylate is an ingredient of the liquid that is applied with a powder to make acrylic or artificial fingernails. Ethyl methacrylate is a starting product of prosthetics. In Australia, the TWA for methyl methacrylate has been reduced in recent years to 50 ppm and it has been allocated a Class 3 carcinogen category. An occupational exposure for ethyl methacrylate has not been set in Australia.

**MOCA**

MOCA or 4,4’–methylene bis (2-chloroaniline) has increased in use for the manufacture of hardened plastics such as rollerblade wheels, skateboard wheels and other applications. It is supplied as solid pellets and then melted in a pot before casting into appropriate moulds. MOCA is easily absorbed through the skin and is a Category 2 carcinogen. It is believed to cause bladder cancer. The TWA for MOCA is 0.02 ppm, although it may be more appropriate to conduct biological monitoring using the urine to determine whether the worker is at risk. With these tests, dipstick urinalysis tests for haematuria (blood in the urine) and urine cytology may also be conducted.

**Oils, resins and rosins**

This category refers to mineral oils and lubricants, synthetic resins from soldering and natural rosins that are emitted from timber products. Many processes involving cutting of
metals require the use of mineral oil as a lubricant. However, the oils may become aerosolised and workers can be exposed to mineral oil mist. Refined mineral oil mist has a TWA of 5 mg.m\(^{-3}\). Resins and rosins have a potentially sensitising effect to either the skin or respiratory system. These are a little more difficult to analyse for, since the exact nature of the resin or rosin must be understood. For instance, the curing of timber releases different types of rosins and categories of turpenes, depending upon the timber. The NOHSC has set a TWA of 0.1 mg.m\(^{-3}\) for the rosin core solder pyrolysis products, measured as formaldehyde.

**Vinyl chloride**

Vinyl chloride monomer is used in the manufacture of PVC. It has been classified as a Category 1 carcinogen due to its effect chiefly on the liver. Acute exposures may result in euphoria, headache, dizziness and loss of consciousness. If the skin is contacted, rapid evaporation of liquid vinyl chloride may cause freezing of the skin, resulting in burns. Chronic exposure may result in scleroderma, Raynaud’s disease, acro-osteolysis and fibrosis of the liver and spleen. The TWA for vinyl chloride monomer is 5 ppm.

**CONFINED SPACES**

Confined spaces is a defined term according to AS/NZS2865 and encompasses many hazards in addition to occupational hygiene hazards. A confined space is defined as any space that may:

- have limited access and egress and is not designed for work
- have an oxygen concentration which may be hazardous
- have a flammable atmosphere
- have toxic contaminants
- cause engulfment.

Confined spaces are particularly hazardous since the atmospheric environment can change quickly and without notice. Since the space is not a normal place of work, many confined spaces are used either for access to remote locations or to perform maintenance. Some examples of confined spaces include vats, silos, drums, tanks, personnel access holes and storage vessels.

In considering the occupational hygiene hazards of confined spaces, it is important to identify any potential sources or processes that may introduce contaminants. Some questions that may be asked include:

- **Does the vessel contain water or had it previously contained water? Is there a potential for sludge or fungal growth?** (Plant matter will respire, consuming oxygen in the space.)
- **Is there any oxidation of the vessel walls?** (Oxidation or rusting of the vessel walls also uses oxygen in this process.)
- **Have any chemicals been stored in the vessel? What was the vessel used for, previously?** (Toxic chemicals may also be a potential source of risk.)
- **Are there any sources of flammable gases or vapours? Have incoming lines been blanked, the pipe removed or locked out?**

Before entering a confined space, the atmosphere should be tested for the concentration of oxygen, flammable gases and toxic contaminants. AS/NZS2865 requires that entry is not permitted unless:

- the oxygen concentration is between 19.5 per cent and 23 per cent
- explosive gases are not more than 5 per cent of the lower explosive limit (LEL)
- any toxic contaminants are less than
their occupational exposure standard.

The LEL is the lowest level at which an explosion may occur if there is sufficient oxygen and an ignition source. According to AS/NZS2865, if the concentration of the LEL is less than 5 per cent, work in the space can continue. If the LEL is between 5–10 per cent, the area must be continuously monitored; and if the flammable gas concentration is more than 10 per cent, the area must be evacuated and ventilated. Confined spaces are potentially high-risk workplaces. Professional advice should be sought where required and AS/NZS2865 consulted for further detail of safe working procedures and recommended control measures.

**OCCUPATIONAL HYGIENE MONITORING TECHNIQUES**

Assessing the risk of exposure to chemical contaminants involves firstly correctly identifying the hazard including its state of matter, measuring the concentration of contaminant and comparing it with an appropriate standard. The discussion about the hazardous nature of chemical contaminants in this chapter may provide you with a good starting point for the hazard recognition. However, once the hazard has been identified, it is important to quantify the extent of exposure to the worker. Measurement of chemical contaminants can be performed in a variety of ways.

Firstly, the contaminant can be directly sampled from within the breathing zone of the worker in real time, to obtain a personal sample that is representative of exposure. Secondly, the air can be collected and sent to a laboratory for analysis. Thirdly, the worker themselves could be monitored using biological monitoring techniques. These techniques are summarised as direct monitoring, sample collection and analysis, and biological monitoring.

Chapter 4 emphasised the importance of understanding the state of matter of a contaminant when selecting a technique for occupational hygiene sampling and analysis. This is equally true for detecting and quantifying the concentration of chemical contaminants such as gases and vapours. Unfortunately, it is still beyond the realm of most Australian workplaces to use a ‘magic’ instrument that will correctly identify the nature of a substance, its concentration and state of matter. Instead, the techniques that are commonly used merely confirm the presence of a suspected contaminant or its concentration (within the limitations of analytical techniques).

When deciding upon the monitoring technique to choose for detecting and analysing chemical contaminants, the following issues should be considered:

- **cost of the device, or sampling and analytical fees**
- **whether it is practical to hire the instruments and samplers or to purchase outright**
- **the characteristics of exposure** (frequency, duration of exposure)
- **the state of matter of the contaminant** (e.g. an acid mist from a liquid bath compared with an asphyxiant gas in a confined space)
- **comparison with relevant standards or benchmarks** (i.e. will the findings be compared with the TWA or the STEL? Or if the exposure is for a short period, are there more than four excursions during the work shift?)
- **number of heterogeneous work groups and number of workers to be sampled.**

A change in any one of these parameters may impact on the overall outcome of monitoring.
For instance, if sampling is conducted while half of the factory is not operating then exposure may be significantly different to a ‘normal’ working day. The concept of a normal working day is discussed in Chapter 1.

**DIRECT MONITORING**

Direct monitoring or real-time measurements allow the concentration of a contaminant to be determined on-the-spot. It is also known as grab sampling, since the sample is quickly taken and analysed immediately. Usually, a sample is collected in the breathing zone of the worker over a short period and the concentration of contaminants determined instantaneously. Some methods do allow collection for the entire shift. The main techniques are categorised as:

- **colorimetric**
- **electrical and electrochemical**
- **thermal**
- **electromagnetic**
- **gas chromatographic**
- **mass spectrometric**.

**Colorimetric**

The principle of colorimetric monitoring lies in the chemical reaction between a known contaminant and a detecting system. In Australia, the most common techniques are either tubes or badges. Because of the specificity of colorimetry, it is vital that the exact substance is known before sampling begins. It is also wise to be sure of other potential contaminants, in case these interfere with the operation of the detection system.

Colorimetric analysis refers to systems where a colour change can be detected using a system whose reagents react with the analyte.

The most widely used of colorimetric systems would have to be the pump and tube assembly. With this system, air is actively sampled through the tube by the drawing action of the pump. The glass tube is tightly packed with a chemically reactive substance. As contaminant-laden air passes through the tube, it specifically reacts with the chemical inside the tube. A resulting colour change or stain will develop along the length of the tube.

To determine the concentration of substance, either the length of stain or its colour intensity is usually compared with the manufacturer’s specified data. Two types of pumps see common use in Australia — the piston pump and bellows pump.

With the piston pump, the piston is drawn back to pull a sample of air through the tube. The exact volume of air will depend upon the tube and sensitivity requirements. Gradations mark the length of the piston, to show the operator the extent of the required piston extension. The handle is then locked in place to allow the chemical reaction to be completed. This normally takes a few minutes. The bellows pump is firmly squeezed to suck air through the tube. Once squeezed, it is allowed to reinflate and the chain at the bellows to become taut. For both types of detector systems, it may be necessary to repeat the stroke (this refers to the depression of the bellows or the drawing of the piston) several times, depending upon the directions of the manufacturer.

As a first port of call, colorimetric sampling is relatively inexpensive and simple to use. A pump costs several hundred dollars and the tubes are usually purchased in packs of ten for $100–$200. However, to the unwary user there may be pitfalls in their use and interpretation of results. Since a sample is collected by drawing a known volume of air through the tube for usually less than one minute, the results should not be used to compare against the TWA. Long-term sampling tubes are available, although these mostly operate using passive sampling,
where the contaminant diffuses into the chemical reagent during the day.

The advantages of direct-reading colorimetric stain tubes are:

- they can be used to identify high-level, short-term exposure
- the requirement for long and expensive laboratory analysis is removed
- they can provide preliminary findings of exposure, including alarm levels for evacuation or remedial controls
- they can be used to check controls.

Unfortunately, they also come with limitations. These include:

- interference from other contaminants can give false positives
- incorrect tube or range selection can result in false negatives
- cross-sensitivity with other substances
- storage requirements for tubes
- limited shelf life of tubes.

Some different types of tubes

There are several types of direct-reading colorimetric tubes. All can be used, although for active sampling it is important that the pump brand is aligned with the tube. For instance, the two main brands, Dräger and Kitagawa, have different diameter tubes. Attempting to insert a Kitagawa tube into a Dräger pump will result in leakage and an invalid sample! The types of tubes can be best described as:

- single layer (where all the filling is the indicator layer)
- multi-layer (a pre-layer may contain a filter for interfering substances)
- two tubes (a pre-tube and indicating tube are included to keep the reagent components separate)
- ampoule detector (includes a filling indicator and additional reagent ampoule; when the ampoule is broken, its contents are released and shaken onto the indicating layer).

How to use colorimetric tubes

Of all the occupational hygiene sampling techniques available, colorimetric tubes are one of the simplest to use. These steps are summarised below:

1. Select the contaminant and approximate concentration range. This technique is very specific and the exact nature of the substance must be known. Additionally, most tubes have a concentration range. If the concentration of contaminant is above or below this range, the substance will not be detected or will result in a stain that is beyond the graduations of the tube.

2. Leak-test the pump. If a pump leaks, it will under-sample and the result cannot be relied upon. With the bellows pump, an unopened tube is inserted into the pump when the bellows are depressed and left for one minute. If the bellows reinflate, the pump may be leaking and require maintenance. To leak-test a piston pump, an unopened tube is inserted and the handle gently pulled. If there is a firm resistance and the handle ‘bounces’ back to its original point, the pump is not leaking.

3. Read the manufacturer’s instructions. When checking the operating instructions, it is important to search for limitations of the method, such as interferences or effects of temperature, pressure or humidity. If the sample is collected at conditions other than normal temperature and pressure, adjustments to the concentration may need to be made.

4. Break the tip from the tube. Most pumps contain a tip-cutter, although care should be taken with the tiny shards of glass. For
ampoule tubes, the ampoule inside the tube must be broken and its contents shaken over the reactive chemical inside the tube.

5. Insert the tube into the pump. Nearly all tubes have an arrow printed along each side to indicate the direction of airflow. Therefore, the tube is placed in the pump with the arrowhead facing the pump, and a prescribed number of strokes taken to draw the correct air volume through the tube.

6. Read the stain. After the required volume of air has been pumped through the tube, the length or intensity of stain is usually read immediately. Since the length and colour of the stain may change quickly, it must be read as soon as possible before this occurs. The pump is then purged with clean air to remove any corrosive contaminants from inside the pump that may contribute to its deterioration.

Accuracy of detector tubes

Detector tube measurements are generally quite accurate. Most are in the order of a 10 per cent relative standard deviation. A less accurate tube may have an error of 20 per cent. Since occupational hygiene sampling already has its share of random and systematic error, an error of 10 per cent may not necessarily be unacceptable. The factors that may affect its accuracy include the volume of air drawn through the pump, completeness of reaction, reading of the stain and the type of colorimetric tube system.

The other types of colorimetric samplers include a paper strip system or enzyme reaction system. Isocyanates can be monitored using a system where the particular isocyanate reacts with the chemical-impregnated paper to allow a concentration to be given.

Formaldehyde can be sampled directly using a badge that contains enzymes. The
intensity of colour change in the badge is compared to a supplied chart.

Passive colorimetric tubes are also available. With these tubes, air diffuses into the chemical-absorbing material for an extended period of time (usually about eight hours) and the colour change is read after that time.

**Electrical and electrochemical**

The principle of operation of electrical and electrochemical direct-reading instruments lies in the reaction between the gas or vapour and another chemical or the transfer of electrons from orbitals of the atom or molecule. This technique is usually used for explosive or reactive gases and vapours. As the substance contacts the current, it may cause an increase or decrease in the electrical energy. A common device for measuring an electrical cell’s change in energy is the potentiometer. This can measure the maximum voltage from the reaction.

Explosive gas can be detected and measured using this type of monitor. With this, explosive gases are detected using a Wheatstone bridge. In a Wheatstone bridge, an unknown resistance is balanced against a standard accurate resistor for precise measurement of resistance. The gas or vapour causes a change in resistance, which then causes the bridge to be balanced by varying the standard accurate resistor. This is then converted into a signal. To detect other gases using this instrument, electrochemical cells are used. This reaction causes a change in the current, which is then converted into a signal.

**Thermal**

Thermal detection instruments operate by a change in temperature that can be detected and transformed into a signal.

**Electromagnetic**

With electromagnetic detectors, the photoelectric effect of the substance and emission spectra can be used to identify and quantify the gas or vapour. Examples of these include UV and infrared photometry. Modern technology is continuing to reduce the size and cost of these instruments. Instruments may be for detecting specific elements (i.e. carbon monoxide in underground car parks) or, as in the case of many confined-space testing instruments, multiple elements such as hydrogen sulphide (H₂S), carbon monoxide (CO), oxygen (O₂) and LEL. Many instruments can also be adapted to give either a visual or audible alarm and, in some cases, are capable of logging data over extended periods that can be downloaded to personal computers.

The MIRAN is an example of a mobile infrared analyser. This instrument has a ‘library’ of substances, which it is able to scan for. A series of mirrors and reflecting infrared beam allow the emission spectrum of the substance to be developed. Each element has its own unique emission spectrum and the characteristic lines of the spectrum can then be used to ‘fingerprint’ the substance.

**Gas chromatographic**

Modern technology is continuing to reduce the size of the gas chromatograph (GC) with portable GCs now available for sampling onsite. With gas chromatography, a sample of contaminant is injected into a carrier gas or medium where it is quickly burned to form a vapour. The time taken for the vapour to pass through the carrier gas is measured as the retention time. A plot of the substance or gaseous mixture is given, with peaks on the graph indicating the presence of a pure substance. If the retention time of the substance is known, the area of the peak can be extrapolated to a mass and concentration.
Gas chromatography is mostly used for measurement of organic substances.

**Mass spectrometric**

The most direct and accurate method for identifying chemical substances is through the use of a mass spectrometer. This allows the atomic and molecular masses of the substance to be identified by bombarding a gaseous sample with high-energy electrons. The collision between the electrons and atoms produces positive ions, which are then accelerated by passing them through two oppositely charged plates. The ions are passed through a magnet, forcing them into a circular path.

**SAMPLE COLLECTION AND ANALYSIS**

In many cases, it may not be appropriate to use direct-reading devices to analyse for workplace gases and vapours. Perhaps a direct-reading system is not available or a more reliable expression of concentration is required. The nature of direct-reading samples is also a reason to avoid their use — the grab sample can only provide an indication of exposure over a small window of an entire working day; and a one-minute sample may not be representative of overall exposure.

Sample collection has many advantages over instantaneous or ‘grab’ samples. These include:

- the ability to confirm the identity of a contaminant when previously the exact chemical was unknown
- easily analysing mixtures of gases and/or vapours at the one time
- detecting low concentrations of substances or insensitive materials
- storing samples for analysing at a later time
- the ability to collect a sample over an entire working shift or a duration representative of exposure.

When deciding on the type of sample collection technique, careful consideration must be given to a number of factors. For instance:

- the chemical and physical structure of the contaminant
- the type of work situation
- the analytical method for measuring the contaminant (including its sensitivity, limit of detection and interferences or cross-sensitivities)
- knowledge of the contaminant’s identity and likely concentration range.

In deciding on the best method for collecting and analysing a sample, it is best to refer to standard methods, which detail both the collection and analytical techniques. In Australia, a limited number of Australian Standards methods are available. However, US methods promulgated by NIOSH and OSHA are commonly used. The UK also has some methods that can be used.

Some manufacturers and suppliers of air sampling products have catalogues available that specify details for sampling of airborne contaminants.

The three main sample collection methods are:

- liquid absorption (washing through an absorbing solution)
- adsorption onto a solid sorbent (e.g. carbon, activated charcoal, silica gel)
- collection in a large bag or pumped under pressure into a cylinder.

Many permanent gases such as oxygen, carbon dioxide, nitrogen, hydrogen, carbon monoxide and argon cannot be easily reacted with a
collected medium. These should be collected by physically taking a sample of the gas in a bag or jar. Organic vapours, because of their polarity, are reversibly adsorbed onto a range of media including charcoal, silica and XAD. This is useful as the contaminant can be conveniently 'desorbed' from the collection media for analysis at the laboratory. Reactive gases and vapours cannot be trapped on charcoal but may be collected by reacting with another media. For instance, acid gases, oxides of nitrogen, sulphur dioxide and ozone can be trapped by a reaction with a base such as sodium hydroxide.

To decide whether sample collection and analysis can be performed, a number of questions should be asked. These include:

- What is the efficiency of the sampling and analytical methods?
- Will the contaminant be detected using the proposed analysis?
- Will the sampled gas or vapour be retained in the same chemical form that it exists in for the sampling process?
- Will the sampling equipment and medium be safe for the wearer, user or environment?

Liquid absorbers

Some gases are best collected by dissolving them into a solvent or washing with another chemical. Acids and bases can be made to react with the opposite material. Some examples of this type of sampling are collection of:

- formaldehyde in water (or bisulphite solution)
- ozone in potassium iodine solution
- oxides of nitrogen in sulphanilic acid
- halide gases in silver nitrate.

The devices used to collect the gases in liquid are designed to allow the gas to be conveniently passed through the liquid and captured. Different types of gas-washing devices include:

- the midget impinger, which creates small bubbles at the point of entry
- a helical spiral gas-washer
- a fritted-glass washer, which creates a stream of very fine bubbles and increases the surface area available for contact.

The sampling technique involves the connection of the sampler to a constant flow sampling pump at known flow rate (usually 0.5–1.5 L.min⁻¹). Sometimes, two or more impingers are connected in series to increase the efficiency of collection or to allow a pre-filter (or absorber) to remove any particular contaminant which may interfere with analysis.

Solid sorbent sampling

As the term suggests, solid sorbent sampling collects a sample of gas or vapour on a media that is non-aqueous. With this technique, the physical and chemical nature of substance must be recognised to ensure the correct medium for adsorption is selected. An excellent prime reference for organic vapour sampling in Australia is AS2986.

Certain gases and vapours are readily adsorbed by some solid materials such as activated charcoal, silica gel, polymers and molecular sieves. The selection of adsorptive material will depend on the polarity of the media and analyte to be collected. For instance, organic gases and vapours are collected using activated charcoal. Substances such as glutaraldehyde vapour are collected on silica gel.

The adsorbent material is usually tightly packed into a glass tube. In a similar technique as colorimetric tube sampling, the tip of the tube is broken off and a measured volume of air is drawn through the tube (active sampling).
After sampling, the tubes are capped and then desorbed in the laboratory for analysis. The sample tube is usually placed within the breathing zone for personal sampling and can also be used for static sampling. Passive sampling can also be conducted using a solid adsorption material. With this method, air diffuses into the medium (which is designed as a tube or a badge). Once sampling is complete, the adsorptive material is sent to a laboratory for analysis.

**Gas sampling bag**

In some cases it is preferable to collect a sample in order to take it to a laboratory for more comprehensive analysis.

In these situations, an impervious bag or cylinder may be used. This method is suitable for a number of gases such as oxygen, carbon monoxide, hydrogen and methane. Care must be taken to ensure the bag or cylinder medium is inert to the sample and will neither adsorb it nor allow it to permeate through.

To collect a bag sample, the container must firstly be flushed or purged. This will ensure that any previous gases do not interfere with the collected sample. The collected sample should then be sucked into the bag at least three times, before sealing firmly to prevent leakage. Ideally, the sample should be analysed as soon as possible after sampling to minimise loss or adsorption of the gas to the inside of the bag. The concentration of gas will normally be expressed as a percentage (%v/v).

**Active sampling**

Active sampling involves the collection of a sample using a pump that draws a known volume of air through an adsorptive tube. Some brands of pump include SKC, DuPont, Gilian and AirChek. These range in price from several hundred dollars to thousands, and are available with timers and delayed start capabilities.

The pumps also usually have an in-built rotameter, although this should not be relied upon for calibration unless it has been checked against a primary method such as the upturned burette. The selection of flow rate and duration of monitoring is dependent upon the collection efficiency of the adsorbing material and the sensitivity and detection limit of the analytical method.

Organic vapours can be sampled according to AS2986, using a tube packed with activated charcoal, with a flow rate between 50 mL.min⁻¹ and 200 mL.min⁻¹. Many workplaces use high-flow sampling pumps that have been converted to a lower flow to conduct this sampling. Once the tip has been broken from the tube, the tube is inserted into connecting tubing and sampling begins. Immediately after sampling is finished, the tube must be capped to prevent the vapour from desorbing from the adsorbing material.

Laboratory analysis of adsorption tubes should be conducted as soon as possible after sampling. It is preferable to store the tubes in a cool environment that will minimise loss of the collected substance.

To desorb the tube, it can be either thermally treated or desorbed using a strong solvent such as carbon disulphide or petroleum ether. Thermal desorption is the preferred method, since carbon disulphide, in particular, is a hazardous chemical and its use should be minimised where possible. Thermal desorption also minimises loss as the heated vapour is fed directly into the analytical instrument, usually a gas chromatograph. This instrument is able to detect and identify the substance, expressing the result as a mass.

The adsorption tube used for vapour sampling and analysis usually also has a front and backup section (Figure 6.2). When analysing the tube, both sections should be analysed individually in order to check for break-through. Break-through can occur where the vapour or gas is passed too quickly through the tube or the concentration has
exceeded the capacity of the tube. If analysis shows the presence of the monitored substance in the backup section of the tube, this indicates there has been break-through. To correctly calculate the concentration of a substance from the sampling results, both the front and backup sections of the tube must be taken into account, as well as the flow rate and duration of monitoring. This is shown in Equation 6.2.

**Equation 6.2**

\[
\text{Mass of contaminant (mg.m}^{-3}\text{)} = (\text{mass (front)} - \text{mass (back)} \\
\pm \text{blank/ flow rate (L.min}^{-1}\text{)} \\
\times \text{sampling duration (min)}) \\
\times 1000
\]

**Passive sampling**

There are two common types of passive sampling devices — passive badges which require analysis in laboratories and passive direct-indicating sampling tubes which do not require this analysis.

Passive badges or samplers are based on Fick’s first law of diffusion. The gas absorption rate is governed by its rate of diffusion across a well-defined diffusion path. The flat badge sampler has a short diffusion path compared to the cross-sectional area and diffusion is generally controlled through a porous membrane of polypropylene.

The tube-type sampler is the opposite, and has a small cross-sectional area compared to a long diffusion path.

These passive sampling devices are designed to be worn as a lapel badge and are free of any pump or tubing. At the end of the
sampling period, the badge is returned to a laboratory where the adsorbent material is removed and analysed. Some tubes are designed to be read directly from the graduations at the end of the sampling period and require no further analysis. Some badges have problems with the effect of air passing over the adsorbing media. Research is continuing in the design of a badge that is not affected by low air velocities.

Diffusion samplers operate on the principle of diffusion of gas across a porous membrane. Fick's first law of diffusion can be applied to the mass uptake rate (Equation 6.3).

**Equation 6.3**

\[
dm/dt = AD(C_o - C)/T
\]

Where:
- \(m\) is mass of adsorbate collected in grams
- \(t\) is sampling time in seconds
- \(D\) is diffusion coefficient for the adsorbate in air, in cm\(^2\).s\(^{-1}\) (this is available from the manufacturer for a given chemical)
- \(A\) is cross-sectional area of diffusion sampler in mm\(^2\)
- \(L\) is length of diffusion path in cm (from porous membrane to sampler)
- \(C\) is concentration of contaminant in ambient air, in g.cm\(^{-2}\)
- \(C_o\) is concentration of contaminant just above the adsorbent surface in g.cm\(^{-2}\)

If we were to assume the concentration of \(C_o\) were zero (it all gets adsorbed out of the air by the sampler), the following equation may be applied (Equation 6.4).

**Equation 6.4**

\[
m/t = ADC/L
\]

Using either Equation 6.3 or Equation 6.4, the change of mass \((m)\) over a time period \((t)\) can be determined. This is the concentration of the contaminant.

**BIOLOGICAL MONITORING**

Biological monitoring is discussed in Chapter 1. In some cases, it may not be appropriate to merely sample the occupational environment but necessary also to determine workers’ actual uptake of a substance by measuring the substance itself, an indicator of the substance or its metabolites. The appropriateness of biological monitoring as a valid method of determining exposure relies on the existence of a method for detection of the substance or its metabolites and an appropriate benchmark with which to compare exposure. Ethical considerations and tolerance of the sampling regime will also impact on its practicability.

Some examples of biological monitoring of chemical contaminants include:

- urinary analysis for MOCA
- urinary analysis for hippuric acid (a metabolite from toluene exposure)
- blood analysis for isocyanates
- estimation of red cell and plasma cholinesterase activity levels from exposure to organophosphate pesticides
- analysis of breast milk for organochlorine pesticides.

In conducting biological monitoring, consideration needs to be taken of issues such as:

- **the time of collection of the sample** — e.g. is the sample collected at the beginning of the shift or at the completion of the shift? Does the substance have a short half-life that will mean it is not detected unless monitored at the correct time? Will it
accumulate during the shift or be metabolised and removed from the body?

- **whether the technique is invasive**, such as drawing blood or a fat biopsy, or less invasive, such as analysis of hair for heavy metals
- **access to analytical techniques**, the conditions that samples need to be kept under for transportation and analysis
- **interpretation of the findings** (an occupational physician may be required to interpret the results)

Some useful guidelines for biological monitoring and health surveillance that relate to specific occupational hygiene hazards are published by the NOHSC. The details are shown in the Bibliography and Further Reading.

**SUMMARY**

Chemical contaminants such as gases and vapours can present a risk to workers due to their ability to easily move throughout the workplace, pervading even very small areas. The three main groups of chemical contaminants are asphyxiants, irritants and toxics.

These gases and vapours can be monitored using direct-reading techniques such as colorimetric, thermal, electromagnetic, gas chromatographic and mass spectrographic techniques. The alternative is to collect a sample of the substance and analyse it at a later time. Sample collection can be conducted by liquid adsorption, adsorption onto a solid sorbent or collection in a bag or other device.

**BIBLIOGRAPHY AND FURTHER READING**


One of the most significant hazards in the workplace is exposure to noise. Noise is an inherent aspect of daily life, both at work and socially. However, excessive or prolonged exposure can lead to hearing loss, hearing quality impairment and other health effects. The onset of these effects sometimes occurs after an acute exposure but mostly after a considerable latency period. For this reason, noise is seen as an insidious occupational hygiene hazard.

Noise is the term that describes the interpretation of sound and whether it is wanted or hazardous. It includes the products of day-to-day living such as music, chirping birds or industrial noise from factories and

---

**Figure 7.1** Sound is transmitted in waves, like a pebble thrown into a pond
workplaces. However, noise is actually an energy source that is transferred through a medium (such as air) and is sensed by the hearing mechanism of the body — the ear. Noise can be calming and relaxing. It can also annoy, disrupt and damage.

Vibration often exists in concert with noise. It can affect segments of the body, such as the hands and arms or the whole body.

This chapter provides a description of noise and vibration physics, their sources, health effects and methods to measure and classify them. The components of a hearing conservation program are also described, together with practical methods to control noise at the source, its path or at the ear. Methods to control the risk associated with exposure to vibration are also discussed.

THE PHYSICS OF SOUND

The easiest way to describe sound is to consider it as an energy source that is transferred from a vibrating body through a medium and to a receiver. The energy \( E \) is generated by the movement of molecules in a vibrating object and is conveyed from the source in waves (longitudinal waves). With longitudinal waves, the particles of the medium vibrate in the same direction as the motion of the wave. The other type of wave is a transverse wave, where the particles vibrate in a direction that is perpendicular (transverse) to the motion of the wave itself. The ear detects the resulting sound energy from the wave.

Imagine throwing some pebbles into a still pond. As the pebbles hit the surface of water, waves are generated from where the pebbles enter. The transfer of energy causes water to be ‘pushed’ from the pebbles. The waves then reverse direction, returning the water to its original position (Figure 7.1).

This analogy is almost identical to the generation and transfer of sound or acoustic energy. As energy is generated from a source, it passes through the elastic medium of air, compressing it in the same direction as the acoustic energy. Compression causes a small increase in the air pressure. When the vibrating motion reverses direction, a partial vacuum or rarefaction occurs.

Alternating compression and rarefaction of the air causes small fluctuations in pressure and extends outward to form a pressure wave vibrating at the same frequency as the vibrating source. The ear’s hair cells are able to detect these fluctuations in pressure, convert them into electrical pulses and send them to the brain where they are interpreted as noise. While this description oversimplifies the generation of sound (a water wave is a combination of transverse and longitudinal wave motion), it has some benefit in explaining how energy can be converted to acoustic pressure. Sound pressure waves will actually spread from a source and reflect (or diffract) around an object or barrier. The nature of the diffraction will depend on the wavelength of the wave, which in turn is related to the frequency of the wave, as shown in Equation 7.1.

\[
c = \lambda f
\]

Where:
- \( c \) is speed of sound \( (\text{m.s}^{-1}) \)
- \( \lambda \) is wavelength \( (\text{m}) \)
- \( f \) is frequency of the wave \( (\text{cycles.sec}^{-1}) \)

The wavelength is the distance between two successive points of the wave and is measured in metres. The frequency or number of compressions and rarefactions in a period is measured in cycles per second or hertz (Hz). The frequency is sometimes called the pitch of sound. For instance, a beating drum or rumbling diesel engine mainly emits low frequencies (low pitch). A squeaking wheel or wailing siren usually emits high frequencies. The human ear is relatively insensitive to low and very high frequencies (high pitch). A young, healthy human ear has an audible range...
between 20Hz and 20 000 Hz. Its highest sensitivity lies between 1000 and 5000 Hz (1–5 kHz).

**CHARACTERISTICS OF SOUNDWAVES**

As sound energy is transmitted through a medium in waves, it exhibits certain properties. Firstly, the longitudinal waves travel at a velocity or speed. The speed of sound differs depending upon the medium, temperature and pressure in which it is travelling. At Ø–ºC and 1 atmosphere of air pressure, the speed of sound is accepted as 331.3 m.s$^{-1}$. As the temperature (T) increases, the speed of sound also increases at approximately 0.60 m.s$^{-1}$ for each 1–ºC. The speed of sound in steel is around 6000 m.s$^{-1}$ and it is around 4700 m.s$^{-1}$ in aluminium.

**Example 7.1**

What would be the speed of sound (c) at 20°C and 1 atmosphere?

Answer:

\[
c \approx (331 + 0.6T) \text{ m.s}^{-1} \\
\approx 343 \text{ m.s}^{-1}
\]

Small fluctuations in air pressure that are caused through the vibration of air particles are known as acoustic pressure. For simple sounds, the acoustic pressure is described as a sinusoidal (sine) curve (Equation 7.2) that considers:

- the angular nature of the wave
- the period or time duration of the wave (t)
- amplitude or maximum value of the curve (A).

**Equation 7.2**

\[ p = A. \sin 2\pi ft \]

Since the pressure of the wave changes direction (compression and rarefaction), the maximum amplitude (A) of the curve is both positive and negative, when compared against a neutral axis. If the arithmetic mean of the pressure wave was considered, its overall amplitude would be zero since the positive and negative amplitudes of the wave would cancel out each other. Therefore, to determine the equivalent amplitude of the pressure wave (or the effective pressure, $p_{\text{eff}}$), the root mean square (rms) value is taken. This is expressed in Equation 7.3.

**Equation 7.3**

\[ p_{\text{eff}} = p_{\text{rms}} \approx 0.707 \ p_{\text{amplitude}} \]

The rms is determined by squaring the mean values of points along the pressure wave and then taking the square root of this value.

The simple soundwave shown in Figure 7.2 illustrates the pattern, or cyclic nature, of a sinusoidal wave.

One cycle is described as the displacement of a sound source from equilibrium through to its maximum point, before rebounding to its minimum level and returning to equilibrium. Figure 7.2 shows a frequency of 2 Hz or two cycles per second. The time taken to complete the cycle is known as the period (t) and is measured in seconds. Period and frequency are inversely related (Equation 7.4).

**Equation 7.4**

\[ t = 1/f \]

Where:

\[ T \text{ is period (sec)} \]

\[ f \text{ is frequency (Hz)} \]

The other characteristic of a soundwave is its wavelength (l), measured in metres (m). A wavelength is the distance between two successive crests or two identical points on the wave.
Example 7.2

A longitudinal wave has a period (t) of 0.5 seconds. What is its frequency in Hz?

Answer:

\[ f = \frac{1}{T} \]

\[ = \frac{1}{0.5} \]

\[ = 2 \text{ Hz} \]

Characteristics of Sound

So far, this chapter has focused on the nature and characteristics of soundwaves, including their amplitude, frequency, period and wavelength. While this theory is useful, the risk associated with exposure to sound encompasses several other parameters. In the workplace, the three variables that affect the risk of exposure to noise are:

- **frequency composition**
- **amplitude**
- **continuousness**.

As mentioned previously, the frequency or pitch of sound refers to the number of cycles of the soundwave per second. It is generally accepted that a healthy, young ear is able to detect soundwaves between 20 Hz and 20 kHz.

However, exposure at some of the higher frequencies can produce permanent hearing loss. Occupational noise consists of many frequencies. This is known as broadband sound. Where sound has only one frequency, it is referred to as a pure tone. These are found less frequently in industrial settings. The pure tone may be formed from a tuning fork or similar device. Narrowband sound has its energy concentrated in a small portion, or portions, of the audible frequency spectrum and may include pure tones. This situation is frequently encountered in industry.

The amplitude of sound can be measured as an intensity level (IL), although more commonly as the sound pressure level (SPL).

**Equation 7.5**

\[ I = \frac{W}{4\pi r^2} \]

Where:

- I is intensity of radiated sound
- W is power (watts)
- r is the distance from the source (m)
For an ideal point source in a free field (where the source is in open air or where reflection is limited), the intensity of sound radiated is given in Equation 7.5.

An example of this type of noise may be a small loudspeaker operating at low frequencies. The continuousness of sound relates to whether the sound is produced intermittently or constantly.

**EMISSION AND IMMISSION**

Sound can be generated in several ways. Emission refers to the radiation of sound from a source. For instance, an electric saw will emit noise from the motor and cutting action of the rotating blade against the timber. Immission describes the influx of sound at a point. Sound immission takes into account the following factors:

- the location of the exposed person or workstation in relation to noise sources
- the relationship between noise immission and normal operations
- the duration of the immission
- if it is caused by a contribution of all sources.

**THE LOGARITHMIC RESPONSE TO SOUND**

Since the human ear is able to detect sound over an incredibly large range, it would be impractical to express this linearly. Instead, a logarithmic scale is used to represent the range of intensity and sound pressure levels that can be detected and interpreted by workers. This method is more practical, as it allows sound to be expressed as a logarithmic ratio of the value to a reference value of \( 20 \, \mu \text{Pa} \).

The intensity level of sound is defined in Equation 7.6. The intensity level is specified as a bel. However, because the bel scale is too large to work with, the decibel (dB) is used. A decibel is one-tenth of a bel.

**Equation 7.6**

\[
\text{Intensity level (IL)} = 10 \log_{10} \frac{I}{I_{\text{ref}}}
\]

Where:

\( I \) is intensity of the sound source \( (\text{W.m}^{-2}) \)

\( I_{\text{ref}} \) is \( 10^{-12} \, \text{W.m}^{-2} \) and is the reference intensity

Figure 7.3 illustrates the difference between noise emission and noise immission.
It is worth noting, however, that occupational sound is usually defined in terms of the sound pressure level, not the intensity level. Conveniently, sound pressure is related to sound intensity by a square relationship, where $I \propto p^2$. From this relationship, sound pressure level can be defined using Equation 7.7.

It is important to ensure that the sound pressure inserted in Equation 7.7 is $p_{\text{ref}}$, not $p$. Unless otherwise stated, it is assumed that the pressure is the effective pressure and not the peak pressure.

**Equation 7.7**

Sound pressure level (SPL) = $20 \log_{10} \frac{p}{p_{\text{ref}}}$

Where:
- $p$ is sound pressure (Pa)
- $p_{\text{ref}}$ is 20 µPa and is the reference acoustic pressure

**Example 7.3**

If the intensity of a sound source is $10^{-6}$ W.m$^{-2}$, what is the intensity level in dB?

Answer:

Intensity level (IL) = $10 \log_{10} \frac{I}{I_{\text{ref}}}$

= $10 \log_{10} \frac{10^{-6}}{10^{-12}}$

= $10 \log_{10} 10^6$

= 10 x 6

= 60 dB

**Example 7.4**

A sound source has an effective acoustic pressure of 25 mPa. What is the sound pressure level at a point in air?

Answer:

SPL = $20 \log_{10} \frac{p}{p_{\text{ref}}}$

= $20 \log_{10} \frac{25 \times 10^{-3}}{20 \times 10^{-6}}$

= 62 dB

**HOW THE EAR HEARS**

When discussing the structure and function of the ear, it is easy to forget that the ear is a complex structure and not just the outer fleshy part that we see each day. The ear has several functions, including:

- maintaining balance
- orientating the body
- hearing.

This chapter has already provided a description of sound as vibrational energy that is transmitted in waves to be detected and interpreted by the ear.

In the workplace, sound is usually conveyed via air. However, it can also be transferred through other media such as liquids and solids. Try to remember when you have been swimming and heard the sounds of a pool filter or voices, albeit a little muffled.

Soundwaves propagated through the air are collected in the outer ear (the auricle or pinna) and channelled through the middle ear. From here, the waves pass into the inner ear, where the continued vibration stimulates the receptor cells in the organ of corti.

Figure 7.4 shows the anatomy of the ear. As soundwaves enter the external auditory canal, the tympanic membrane vibrates at the same frequency as the soundwaves. This energy is transmitted through the tiny bones of the middle ear (the ossicles). The ossicles are actually three bones:

- malleus (hammer)
- incus (anvil)
- stapes (stirrup).

The ossicles transfer the vibrating motion of the tympanic membrane to the round window of the cochlea. The round window lies deep in the stapes and causes fluid of the inner ear to move. The inner ear is situated in the
petrous portion of the temporal bone of the skull; when looking from the front of a person’s face, it lies behind the eye socket. It consists of two major parts: the bony labyrinth and membranous labyrinth. The bony labyrinth consists of three regions:

- **the vestibule**
- **cochlea**
- **semicircular canals.**

The membranous labyrinth lies more or less within the bony labyrinth. It is formed from sacs and ducts.

The chief function of the vestibule is to respond to changes in orientation, particularly of the head position. Receptors within the semicircular canals respond to angular movement of the head. The cochlea is the organ that responds to soundwaves. It contains a fluid that moves in waves, increasing pressure when the round window exerts force. As the stapes oscillates against the round window, a pressure wave is generated. Low-frequency sounds that are transmitted across the round window create soundwaves that travel all the way through the cochlea and then back again, without stimulating the organ of corti. This is why we cannot hear certain frequencies. Other higher frequency soundwaves stimulate the cochlear hair cells, causing the hairs to be ‘pulled’ due to changes in vibrationary energy. As the hair cells are excited, neurotransmitters are released and excite the cochlear nerve fibres. The firing of the action potentials that follows is transmitted to the brain via the cochlear nerve. The organ of corti is able to detect different frequencies in different parts of the organ. For instance, high-pitched sounds are
detected by the hair cells closest to the round window.

EFFECTS OF EXPOSURE TO NOISE

The main adverse effect from exposure to noise is hearing loss or deafness. Hearing loss can occur either because of the failure to conduct sound vibrations in the fluid of the inner ear or from damage of the cochlear hair cells right through to the cochlear nerve. These two types of deafness are classified as conductive deafness and sensorineural deafness.

As the title suggests, conductive deafness occurs where the vibrational energy is not correctly transmitted through the ear. Many possible reasons exist for this problem, including:

- rupturing of the eardrum
- illness that restricts the vibration of the eardrum (i.e. if the person has a cold)
- inflammation of the ossicles
- ostoscelrosis, a condition where the ossicles become fused with overgrown connective tissue
- ossicles being out of alignment following an acoustic trauma.

Sensorineural deafness refers to a problem in the cochlea — either from damage to the cochlear hair cells, the vibration of fluid or the cochlear nerve. Occupational exposure to noise can lead to sensorineural deafness or a noise-induced hearing loss (NIHL). The hairs of the cochlea are particularly sensitive to loud noise or noise of certain frequencies. The loss of hearing can be temporary or permanent. Hearing loss is a common age-related problem, although some research indicates the loss may be due to the environment and not necessarily age-related. This is known as presbyacusis. Figure 7.5 illustrates the drop in response to frequencies that is illustrated in a person suffering presbyacusis, as an audiogram.

A temporary threshold shift (TTS) can occur after exposure to a high-amplitude noise or impact noise such as a gunshot or crash of metal-on-metal. This desensitises the cochlear hairs, which may appear to 'bend'. After a period of time, the sensation of dullness of hearing disappears and hearing returns.

A permanent threshold shift (PTS) occurs where the cochlear hairs are damaged by prolonged exposure to noise. The hairs may shear from the cochlear membrane. For workers who sustain a hearing loss, the effects can be devastating. Since the loss occurs at frequencies in the range of human speech (around 4 kHz), general conversation becomes difficult. Words with the letters k, t and p are difficult to hear. Crowd noise, especially, makes it difficult to distinguish conversation from the background noise.

Another, more insidious effect of exposure to noise is a condition known as tinnitus or ringing of the ears. Workers with tinnitus report the sound to be like ringing, buzzing or

Case study 7.1

A temporary threshold shift occurs where the cochlear hairs are desensitised and may actually bend. A primitive method of demonstrating the effect of a TTS is to switch on a radio, and turn down the volume until it is barely heard by the listener. After exposure to noise during a typical workday, the radio is switched on and the volume adjusted until the radio is audible again. The difference between the initial and final volume of the radio indicates a potential TTS.
clicking when an auditory stimulus is not present. The main concern with tinnitus lies in its annoyance factor, particularly in quiet environments such as when the person is trying to sleep or relax. It is believed that tinnitus is an early indication of cochlear nerve degeneration.

Some other symptoms of exposure to noise include:

- heart palpitations
- dilation of the pupil
- secretion of thyroid hormone and adrenalin cortex hormone
- churning of the stomach and intestines from muscle movement
- skeletal muscle reaction
- constriction of blood vessels.

Recent studies have also indicated a link between exposure to chemical substances and hearing loss. These agents are known as ototoxic agents and include:

- trichloroethylene
- toluene
- butanol
- lead
- mercury
- manganese
- arsenic.

Exposure to some chemical agents and noise exposure can cause a threshold shift where normally either the noise source or chemical alone would not cause such a change. These are known as synergistic effects. Some examples of substances that cause synergistic effects are:

- carbon disulphide
- carbon monoxide

Figure 7.5 The effects of presbyacusis on an audiogram
• carbon tetrachloride
• styrene
• xylene
• methyl ethyl ketone and methyl isobutyl ketone.

SOUND PRESSURE LEVELS, WEIGHTINGS AND NOISE DOSE

Occupational noise exposure is measured as the sound pressure level. The unit of measurement is the decibel. Sound pressure levels describe the amplitude of soundwaves at certain frequencies. They can be expressed either as unweighted (or linear) sound pressure levels or A-weighted to imitate the response of the human ear. A comprehensive discussion of weightings is provided in the next section.

In most States and Territories of Australia, exposure to sound pressure levels is regulated according to the following criteria:

• long-term exposure to continuous sound that may lead to noise-induced hearing loss
• acute exposure to high-intensity sound pressure levels that may cause immediate damage.

To protect against both these effects, there are two types of standards for regulating exposure to sound pressure levels (with the exception of Queensland). These are the:

• equivalent, A-weighted continuous sound pressure level over eight hours \( (L_{A_{eq},8hr}) \) of 85 dB(A), referenced to 20 µPa
• peak, unweighted sound pressure level \( (L_{peak}) \) of 140 dB, referenced to 20 µPa.

Queensland occupational health and safety laws have recently revised the application of \( L_{peak} \) and now require its measurement using C-weighting (not unweighted). At the time of writing, other States were yet to follow this change.

The equivalent, A-weighted continuous sound pressure level is a steady-state sound pressure level that is frequency weighted and is measured over a time interval, T. The generalised expression of the equivalent sound pressure level over a time interval is \( L_{X_{eq},T} \) where X is the frequency weighting. Its determination is shown in Equation 7.8. The frequency weightings that are used are A, C or unweighted, as appropriate.

**Equation 7.8**

\[
L_{X_{eq},T} = 10 \log_{10} \sum_{i} \frac{T}{8} x 10^{0.1 L_{X_{eq},Ti}}
\]

Where:

- \( X \) is frequency weighting
- \( T \) is time period

Therefore, the equivalent, A-weighted continuous sound pressure level over eight hours \( (L_{A_{eq},8hr}) \) is shown in Equation 7.9.

**Equation 7.9**

\[
L_{A_{eq},8hr} = 10 \log_{10} \sum_{i} \frac{T}{8} x 10^{0.1 L_{A_{eq},Ti}}
\]

Throughout Australia, noise is generally regulated according to the NOHSC criteria, with some exceptions as detailed above. Unfortunately, even exposure to less than the \( L_{A_{eq},8hr} \) of 85 dB(A) will not protect all workers from noise-induced hearing loss: therefore, it does not provide a clear line between safe and unsafe.

Another method of describing noise exposure is called noise dose. The dose is an integrated measure that combines the criterion sound level and an exchange rate. The criterion sound level is the allowed
sound level over eight hours, or the $L_{\text{Aeq,8hr}}$ of 85 dB(A).

Since dose is still not fully standardised throughout Australia, it is advisable that the criterion level is noted with the dose, either as $\text{Dose}_{90}$ or $\text{Dose}_{85}$. In Australia, the exchange rate is 3 dB. Further discussion of the determination of exchange rate is included later in this chapter. The daily noise dose (DND) is the sum of any partial exposures (partial noise dose or PND), and is equal to unity or 1.0 when the $L_{\text{Aeq,8hr}}$ is 85 dB(A). It is an integrated measure and its determination is shown in Equation 7.10.

Equation 7.10

$$\text{DND} = \sum \text{PND}$$

The partial noise dose can be determined from the combination of exposure over time, $T$. This is shown in Equation 7.11, and its application can be seen in Example 7.5.

Equation 7.11

$$\text{PND}_{85} = \frac{T}{8} \times 10^{0.1 (L-85)}$$

Where:
- the criterion sound level, $L_{\text{Aeq,8hr}}$ is 85 dB(A).
- If the $L_{\text{Aeq,8hr}}$ is 90 dB(A), the value would be $(L - 90)$.

Example 7.5 illustrates the concept of the exchange rate, which refers to an increase or decrease in sound pressure level. In Australia, a doubling of noise intensity is considered equivalent to an increase of 3 dB. Similarly, a halving of noise intensity relates to a decrease of 3 dB. This is known as the 3 dB doubling rule.

Example 7.5

A worker is exposed to 88 dB for 4 hours. What is the PND$_{85}$?

Answer:

$$\text{PND}_{85} = \frac{4}{8} \times 10^{0.1 (88-85)}$$

$$= 1.0$$

Therefore, where two noises of the same intensity are sited together, the resulting increase in intensity is 3 dB. For example, two pieces of plant, each with an intensity level of 90 dB, together give a combined intensity level of 93 dB. The theory for this calculation is shown by Example 7.6.

Example 7.6

Compare two intensities, where $I_1$ is double $I_2$ and determine the difference in intensity level (measured as dB).

Answer:

The difference in dB $= 10 \log_{10} \left( \frac{2}{1} \right)$

$= 3$ dB

Combined intensity levels

In simple cases, the addition or subtraction of like intensity levels results in a 3 dB increase or decrease from the highest value, respectively. However, where there is more than one intensity level, the combined level is best determined using Equation 7.12. A worked example is shown in Example 7.7.

Equation 7.12

Combining $\text{IL} = 10 \log_{10} \left( 10L_1/10 + 10L_2/10 + \ldots \right)$

Where:
- $L$ is the intensity level

Nomograms can also be used for adding and subtracting sound pressure levels. An example of a nomogram is shown in Figure 7.6.

Another useful conversion between the daily noise dose and equivalent, A-weighted sound pressure level ($L_{\text{Aeq,8hr}}$) is shown in
Equation 7.13. The nomogram shown in Figure 7.7 could also be used.

Example 7.7
A worker is exposed to 83 dB for 2 hours, 70 dB for 1 hour and 88 dB for 5 hours. What is the \( \text{PND}_{85} \) and \( \text{DND}_{85} \)?

Answer:
Using \( \text{IL} \approx \text{SPL} \pm 0.2 \text{ dB} \), we can apply Equation 7.11.

\[
\begin{align*}
\text{PND}_1 &= \frac{T}{8} \times 10^{0.1 (L - 85)} \\
&= \frac{2}{8} \times 10^{0.1 (83 - 85)} \\
&= 0.16 \\
\text{PND}_2 &= \frac{T}{8} \times 10^{0.1 (L - 85)} \\
&= \frac{1}{8} \times 10^{0.1 (70 - 85)} \\
&= 0.004 \\
\text{PND}_3 &= \frac{T}{8} \times 10^{0.1 (L - 85)} \\
&= \frac{5}{8} \times 10^{0.1 (88 - 85)} \\
&= 1.25 \\
\text{DND} &= \text{PND}_3 \\
&= 0.16 + 0.004 + 1.25 \\
&= 1.4
\end{align*}
\]

Equation 7.13
\[
\text{LA}_{\text{eq},8\text{hr}} = 10 \log_{10} \text{DND}_{85} + 85
\]

Sound power levels
The term sound power is often found on large pieces of equipment as a specification plate from the manufacturer. Sound power refers to the power of the equipment (in watts) that is generated and transmitted to the workplace. In a simple case, the power is uniformly radiated in all directions, according to the inverse square law. This means that as the distance from the noise source doubles, the sound power reduces by one-quarter. The sound power level can be determined using Equation 7.14.

Equation 7.14
\[
\text{Sound power level} (\text{Lw}) = 10 \log_{10} \frac{W}{W_{\text{ref}}}
\]

Where:
- \( W \) is power of the source (watts)
- \( W_{\text{ref}} \) is \( 10^{-12} \) watts
Weightings

Sound pressure levels can be measured at a number of frequencies. They are typically measured between 125 Hz and 16 kHz. However, the human ear does not have equal sensitivities at each of these frequencies. For instance, human hearing is most sensitive between 1 kHz and 5 kHz. Weightings are used to place emphasis at certain frequencies, according to the required use.

The main weightings used for occupational hygiene purposes are A, C and unweighted (linear or flat). A-weighting reflects the sensitivities of the human ear, with a lower response less than 1 kHz and most sensitive response between 1 kHz and 5 kHz. C-weighting is used to measure high-intensity sound pressure levels and determine the appropriateness of hearing protective devices. Linear weightings refer to an equal weighting over the spectrum of frequencies. As the name suggests, there is no account taken of the response at different frequencies.

These weightings and their relationships to frequencies are shown in Figure 7.7.

Case study 7.2

A worker in a cannery is exposed to a variety of sound pressure levels during the workday. For the first 2 hours of a shift the $L_{Aeq,2hr}$ is 80 dB(A), and for the remainder of the shift (6 hours) the $L_{Aeq,6hr}$ is 90 dB(A). The combined $L_{Aeq,8hr}$ can be approximated as:

$$L_{Aeq,8hr} = 10 \log_{10} \left[ \frac{2}{8} \times 108 \right] + (6 \times 109)$$

$$= 88.9 \text{ dB(A)}$$

Figure 7.7 Weightings
Occupational noise measurement typically uses an A-weighting. Exposure to noise is expressed as the A-weighted equivalent sound pressure level or $L_{Aeq,T}$. The equivalent sound pressure level integrates sound pressure levels over a period of time, $T$. The simplest method of determining $L_{Aeq}$ is to measure it directly using an integrating sound level meter (SLM).

An integrating SLM measures discrete sound pressure levels at time intervals and then averages the values to give the equivalent sound pressure level.

**Octaves**

Octaves are bands that describe groupings of frequencies in the ratio of 1:2. An octave describes the centre or mid-frequency between the range of frequencies. It is given as the geometric mean of frequencies. The centre frequencies that are typically discussed with noise exposure are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000 and 16,000 Hz. If further detail about the characteristics of the sound is required, the normal octaves can be divided into thirds or one-third octaves.

**MEASURING NOISE**

Occupational noise can be measured in a variety of ways and for several reasons. It can either be measured as emission (of a source) or as immission and exposure. The acoustic energy that is emitted by a sound source is measured either as the emission sound power (in watts) or emission sound pressure (in dB) level. Noise immission is generally measured as the equivalent continuous sound pressure level ($L_{Aeq,T}$). For occupational noise exposure, the sound pressure level is typically A-weighted, with the duration of $T$ dependent upon the aim of the measurement. Peak sound pressure levels ($L_{peak}$) are measured unweighted (with the exception of regulatory noise monitoring in Queensland, as identified earlier, which now specifies that peak sound pressure levels are to be measured using C-weighting).

The ultimate aim of determining noise immission is to ascertain whether workers’ noise exposure exceeds the daily noise dose. For this reason, it is imperative that the measurements are representative of the workers’ actual exposure (in a similar way that atmospheric contaminants are measured in the breathing zone). Another application of sound pressure level is to monitor individual items of machinery or equipment. This data may be used to develop noise contours and later used for implementing controls according to the hierarchy of control. The three main techniques that can be used to measure noise in the workplace are the:

- **personal sound exposure meter (PSEM)**
- **sound level meter**
- **auxiliary instruments (such as tape recorders, data recorders and level recorders).**

**Personal sound exposure meter**

The simplest method of measuring a worker’s actual noise dose is to attach a personal sound exposure meter, also known as a noise dosimeter or dosemeter, with the microphone close to the ear of the worker.

Sometimes, measurements taken with a PSEM can be higher than if a sound level meter were used. This is mostly due to reflection of noise from the body or the head, which is in close vicinity to the microphone. The microphone can also be affected by wind or rubbing against clothing.

Personal sound exposure meters must comply with the specifications of AS/NZS2399 and be calibrated before and after use. The advantage of using PSEMs is that they are particularly useful for workers who are mobile and working in many areas.

Similarly, if the person is not stationed near
A piece of static machinery for an extended period of time, the PSEM is a valuable meter. It also gives a reasonably accurate indication of the worker’s $L_{eq,T}$ and $L_{peak}$. Some models have a facility which allows the collected data to be downloaded to computer or serial printer. The individual sound pressure levels can be plotted against time to identify times or work locations where exposure may be high. Some brands provide a statistical analysis of the proportion of time spent in areas above 85 dB(A) or 90 dB(A), time exceeding the daily noise dose and number of excursions above the peak sound pressure level.

**Sound level meter**

Sound level meters measure sound pressure levels in real time. They are used to conduct noise surveys in a workplace. There are two main classifications of sound level meters:

- **non-integrating (or standard) sound level meters**
- **integrating (or averaging) sound level meters**.

Integrating sound level meters take measurements of sound pressure levels at discrete points in time but can average the values to provide an integrated value of sound pressure level. For instance, the instrument can give a value over a time period such as the $L_{Aeq,60s}$. This is the optimal sound level meter to use when conducting a sound survey since it can provide an instantaneous value of the equivalent sound pressure level, $L_{eq}$. AS1259.1 and AS1259.2 detail the compliance requirements for integrating and non-integrating sound level meters, respectively.

The sound level meter consists of a microphone, preamplifier, amplifier, frequency weighting, level range control, time averager and indicating display. The components of the sound level meter are shown in Figure 7.8.

Sound level meters are classified according to their type. There are four types of SLM, ranging from 0 to 3. Type 0 sound level meters are not usually used in occupational environments but are found mainly in laboratories. They have a high sensitivity. Type 1 sound level meters are used in workplaces that require an accuracy of ± 0.7 dB and are generally used by professionals (e.g. consultants) to conduct noise surveys. Type 2 sound level meters are often used by occupational hygienists or in-house health and safety personnel as they are less expensive.

---

**Figure 7.8** Components of a sound level meter
than a Type 1 meter, yet are accurate enough to comply with AS/NZS1269.1. Type 3 sound level meters should not be used.

Other varieties of sound level meters include those that give a readout of the instantaneous sound pressure level. The response of these sound level meters is governed by the time response weighting. The time response weighting refers to the time between detection of the sound pressure level and reporting of the value on the sound level meter. The common settings that are found on most sound level meters are:

- **fast**
- **slow**
- **impulse**
- **peak**.

The fast setting responds quickly to the sound source (time constant 0.125 second) but also decreases quickly. The slow response takes longer to acknowledge the sound source (time constant 1 second) and report the source. It is generally used for root mean square values or where rapid fluctuations of the meter output need to be damped. An impulse setting responds with a time constant of 35 milliseconds and is used for environmental surveys to gauge annoyance.

When using an integrating sound level meter, the preferred setting is slow. For a non-integrating sound level meter, the preferred time setting is ‘fast’.

The sound level meter will also have a weightings network, usually A, C and unweighted (linear or flat). To determine the sound pressure level at the ear of the worker, A-weighting is applied in order to compare the results, in dB(A), with occupational standards. The C-weighting facility is used to assist in noise control. Peaks are measured unweighted.

Some instruments also have the facility to add an octave-band analyser to the sound level meter (1/1 or 1/3 octave band). To conduct an octave-band analysis, the sound level meter must be set to a linear response.

To conduct the noise survey, a variety of methods can be used. The first assumes that workers are located at a stationary location during the entire shift. The sound pressure levels at a piece of equipment or plant can then be measured. It is preferred that the measurements are taken at the ear of the worker, where they would normally be located in relation to the equipment. Measurements should be taken at both ears to check for a difference in exposure at each point. While conducting this monitoring, it is important that reflection from the body of the worker, the plant or the person measuring the noise does not affect the integrity of the results. To overcome this, the sound level meter can be mounted on a tripod and read from a distance of at least 1 metre away.

The sound level meter can also be used to develop a noise contour plan of the workplace. This is especially useful in designating areas according to the sound pressure levels. To plot a noise contour, the sound level meter is used to identify a particular sound pressure level, for instance 85 dB(A). The person holding the sound level meter then moves throughout the workplace, ensuring that the sound pressure level is maintained at the same level. This enables contours of equal intensity to be drawn on the plan of the workplace. Some workplaces use noise contour plans to assist in deciding where to make the area a hearing protection zone.

**Calibration and attachments**

It is imperative that the performance of sound level meters and personal sound exposure meters are checked prior to, at intervals during and following the collection of sound pressure levels. The device used to calibrate these instruments is called an acoustic calibrator. The calibrator must also be calibrated regularly by an accredited laboratory, such as a NATA laboratory, as required by AS/NZS1269.1.
Some acoustic calibrators have two calibrating levels but the most common level used is at 1000 Hz and for a specific sound pressure level. It is important that the SLM or PSEM is set at the correct weighting. For instance, a frequency of 1000 Hz is equal to an unweighted response at 94 dB. The calibration is conducted by:

- **switching on the acoustic calibrator (a tone is heard)**
- **connecting the acoustic calibrator to the microphone of the switched-on SLM or PSEM, ensuring a firm fit without leakage**
- **reading the response from the SLM or PSEM and adjusting the calibration until the response is equal to the sound pressure level from the acoustic calibrator.**

Some sound level meters and personal sound exposure meters have an internal adjustment for calibration. Therefore, a manual adjustment is not required. It is also important to ensure the acoustic calibrator is the same brand as the SLM or PSEM. If not, there is no guarantee of a correct calibration. If an all-day survey is being conducted, the calibration of the meter should be checked at least twice, with a discrepancy of no more than ± 0.5 dB. If the meter drifts beyond this amount, the results must be disregarded and the test repeated.

Attachments, such as windscreens or extended frequency or level response microphones, can also be used with sound level meters and personal sound exposure meters.

**Auxiliary instruments**

In some situations, it may be more appropriate to record sound and analyse its characteristics later. Auxiliary instruments such as tape recorders, data recorders and level recorders can be used for this purpose. These instruments must also comply with the precision requirements of AS1259.1 for at least Type 2 and preferably Type 1 instruments. Tape recorders must comply with AS2680. The sound pressure levels are recorded in a similar way as the sound level meter — close to the ear of the worker or near machinery where workers are sited. An example of the application of this type of auxiliary instrument is analysing the characteristics of ‘roof-talk’, the creaking and movement from unstable roof strata, in underground coalmines.

**Frequency analysis**

Earlier in this chapter, the characteristics of noise were described as its amplitude, frequency and period. The level of risk associated with exposure to noise is also governed by its frequency, amplitude and duration of exposure. Sound pressure levels that are linear (or non-weighted) are those where no account is taken of the frequencies that contribute to the overall sound. However, it is possible to determine the types and magnitudes of frequencies of a sound source by conducting a frequency or octave analysis. This can be conducted by recording the sound or conducting a real-time analysis using a facility for measuring frequencies.

The main reasons for analysing frequencies are to:

- determine whether hearing protection devices are adequate
- characterise the sound source
- assist in determining engineering controls to minimise exposure.

To measure the frequencies, the sound level meter is set to a linear response and an octave-band analyser is connected to the sound level meter. Either 1/1 or 1/3 octaves can be measured. The mid-range frequencies for 1/1 and 1/3 octaves are shown in Table 7.1.
### Table 7.1 One and one-third octave centre frequencies

<table>
<thead>
<tr>
<th>1/1 octave band centre frequency (Hz)</th>
<th>1/3 octave band centre frequency (Hz)</th>
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<tr>
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<td>12500</td>
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### CONDUCTING A NOISE SURVEY

Once noise has been recognised as a risk to workers, the next step in the risk management process is to conduct an initial noise survey. The initial survey aims to identify potential areas of high risk and non-compliance with statutory requirements. The questions that occupational hygienists should ask themselves relate to the areas of risk, nature of the risk and source of the risk. Asking open questions, such as where, why, who and how, will help to provide answers about the nature of the workplace and potential problem areas.

The noise survey can also be conducted to assess the effectiveness of engineering controls in place or the type of hearing protection devices that are being utilised. A detailed noise assessment could then be conducted using a sound level meter or actual exposure measured with a personal sound exposure meter. This will allow the $L_{Aeq}$ and peak sound pressure levels to be determined. AS/NZS1269.1 describes noise assessments under the following categories:

- the preliminary noise assessment
- a detailed noise assessment
- the follow-up noise assessment.

A preliminary or initial assessment should be conducted where noise has newly been identified as a risk at the workplace and a noise survey has not been previously conducted. In addition, if previous assessments have been performed but are more than five years old, an initial assessment should be conducted to obtain an overview of the state of conditions in the workplace. A detailed assessment may then be required if there is doubt as to whether the noise sources are placing workers at risk, if the noise sources are complex or if the noise levels are excessive.

The detailed assessment involves measuring sound levels for the $L_{Aeq,8hr}$ or $L_{Aeq,T}$ and the $L_{peak}$. The levels should be taken at work areas or on workers who may be at risk from noise exposure.

The follow-up noise assessment aims to check controls and the current status of noise exposure, although a noise assessment may have been previously conducted. An assessment should be carried out at least every five years or where any of the following have occurred:
• a change to the process that may have affected noise exposure
• additional equipment or plants have been added to the workplace
• changes in work procedures that could have affected noise exposure.

The first step in conducting the noise assessment survey is to calibrate the SLM or PSEM. If a discrepancy of more than ± 0.5 dB in the reference level, or ± 10 per cent in the reference noise exposure reading, is found between two successive checks, then the results of the measurements taken between the two checks are invalid.

The sound pressure levels are taken either on a worker or at a particular location where the worker spends their normal workday. The occupational noise exposure includes both immissions from equipment and plant, as well as other noise from radios, sirens or warning signals. Where a person occupies one work area, the sound pressure levels are taken at this location. However, most workers are exposed to noise in different work locations. Therefore, the sound pressure levels are measured in each of these locations and the duration of exposure determined to calculate the partial noise dose and daily noise dose.

The microphone should be located about 0.1 m, but no more than 0.2 m, from the entrance of the external canal of the ear receiving the higher noise level, at a level that is horizontal to the ear. If this is not practical, the person can be removed from the area and a measurement taken at the location where they would have been. If a PSEM is being worn, the preferred location of the microphone is the top of the shoulder, close to the ear. If it is difficult to define the worker’s head position in the work location, AS/NZS1269.1 suggests that the microphone heights should be:

• 1.5 m above the ground for a standing person, at a location

where the worker would normally be standing
• 0.8 m above the middle of the seat for a horizontal seat. If the seat is at an angle, the microphone should be placed 0.8 m as close as possible to the midpoint of its horizontal and vertical adjustment.

The equivalent, continuous sound pressure level should be measured over a representative period of the operation, process or work pattern of exposure. The duration of monitoring should include any process or procedures that could significantly vary the noise level (e.g. machines switching on). No matter what the duration of the measurement (T), it should be either the entire length of the task or a portion of the task where the $L_{eq}$ can be assessed. Whatever is chosen, the reading must stabilise to within ±0.5 dB.

When conducting the noise assessment, adequate information should be kept both as evidence if required due to litigation and as a benchmark for the future. Some information that should be kept includes:

• details of the workplace (location and nature of work)
• description of the work environment including nature of work process and tasks; acoustic characteristics of the workplace (e.g. reflective walls and panels, absorbing materials, open areas); working hours for a ‘normal’ day; number of workers in various areas; alterations to the workplace compared with a previous assessment; job description or designation where the measurements are taken; and details of current controls, including hearing protection devices
• noise assessment details such as the brand and type of sound measuring instrument; operating conditions
during the measurement period; locations of measurement; time-in-motion study of various tasks during a typical day; and individual time periods of exposure, if the partial noise dose is to be determined

- results of the noise assessment
- name and signature of the person conducting the survey
- date of the assessment.

**Instruments used to conduct the noise survey**

The most popular instruments used to conduct a noise assessment are the integrating (or averaging) sound level meter, non-integrating sound level meter and personal sound exposure meters. A Type 1 sound level meter is the preferred instrument to use for these types of surveys, although a Type 2 meter could be used where there is no conflict or margins with exposure and regulation. Type 3 sound level meters are only recommended for use in the preliminary assessment of noise.

**OCCUPATIONAL NOISE MANAGEMENT**

A number of techniques are available to minimise the risk of exposure to noise. The underlying emphasis should be to implement an occupational noise management or hearing conservation program. The program integrates the principles of risk management — recognition, evaluation and control — to identify areas or tasks with potential hazardous exposure. The program can also be used to assess the magnitude of exposure and control. AS/NZS 1269.0 suggests the noise management program should include the following components:

- hazard identification (by conducting a preliminary noise assessment of the workplace)

- hazard evaluation (including a noise policy with exposure goals and comparison of results from the noise assessment with regulatory and company standards)

- hazard and risk control

- program evaluation.

Controls can follow the hierarchy of control, namely:

- elimination

- substitution

- engineering

- administration

- personal protective equipment.

This section of the chapter will focus mainly on engineering controls, including methods for reflection and absorption of noise, administrative controls such as audiometric testing and the selection of hearing protection devices.

**Hearing conservation program**

The hearing conservation program should be a component of the occupational hygiene management system that is described in Chapter 14. The program begins with a policy that cements the organisation’s commitment to minimise the risk associated with noise exposure. The policy should be supported by the highest level of management and be regularly reviewed to ensure its alignment with the organisation’s goals and regulatory requirements.

It may include the following components:

- a statement of management’s commitment to the policy

- the organisation’s philosophy of minimising noise exposure, including its goals and objectives

- methods that will be used to determine that the goals and objectives are measurable and met
allocation of responsibility for minimising noise exposure

date of formulation/publication

signature of the Chief Executive Officer or person with overall responsibility for occupational hygiene and risk management.

It should be noted that a policy by itself would not prevent noise exposure. A risk management approach of identifying, evaluating and controlling exposure to noise is the best approach to take. Hazard identification techniques should be documented and audits or walk-through surveys conducted to identify potential areas where noise exposure may be a problem. Noise surveys and audiometric testing should be integrated into the program. Scheduled testing and reporting can be incorporated into the program to ensure the timeliness of the assessment, both from a statutory compliance and best-practice framework.

Standards or benchmarks for performance should also be identified. At a minimum, this would be the statutory requirements of the Australian State or Territory. Individual organisations may also develop their own standards for noise exposure that are below the regulatory requirements. Therefore, both the organisation and statutory benchmarks should be determined.

Elimination and substitution

These control techniques are best considered during the initial planning and design phase of a process, as retrofitting and redesigning the process is often very costly. Where possible, noisy tasks, tools or plants should be eliminated. This can be achieved by transferring the risk to another organisation or source (e.g. contracting the work to another workplace which is better suited to control the risk). A ‘buy-quiet’ approach can also result in the elimination of high-risk noise sources by ensuring that such equipment or tools are not brought into the workplace.

With substitution, the process or inputs can be changed to minimise noise. Some examples of substitution include the use of pliers instead of a hammer to minimise impact noise and using self-tapping screws or rivets rather than nails.

Engineering controls

One of the most cost-effective methods of minimising noise exposure is to reduce its transmission, either through absorption, damping or isolation methods. Our description about soundwaves so far has assumed that sound pressure waves move freely in the workplace. However, this assumption is not exactly correct. When sound hits another object or media, it can act in three ways: it can be reflected, absorbed or transmitted.

The movement of sound is related to the ratio of wavelength to the size of the reflecting surface. For instance, low-wavelength (high-frequency) sounds tend to reflect at the same angle of incidence. In fact, noise can be emitted equally in all directions from the source or in a directional pattern. The intensity of sound will depend on both the sound power level and the movement of the soundwave. In the simplest case of noise propagation, where there is no reflection (an anechoic chamber), the distribution of sound will be almost equivalent to a spherical free field.

The free field refers to conditions where the inverse square law applies to the sound propagating from the source. However, if a piece of plant were to be placed in a room with a sound-reflective floor but absorbent walls and ceiling, then the noise will be distributed in a half-spherical pattern. This, in effect, causes a doubling of sound intensity as the spherical free field is reduced by half, and is sometimes called the directivity factor (Q). Therefore, for a half-spherical radiation
pattern, \( Q \) equals two. If one wall plus the floor causes reflection, the noise will be distributed in a one-quarter spherical pattern \( (Q = 4) \). Where the machine is placed in the corner of a room and there are three sources of reflection, the sound will radiate in a one-eighth spherical pattern \( (Q = 8) \). This is shown in Figure 7.9.

**Engineering control options**

In order to understand the application of engineering controls, it is firstly important to appreciate the components of a noise source that make it conducive to control by damping, isolation or absorption. Since noise is actually the perception of energy that is moved through waves, we can expand this to show that a noise source requires:

- vibrational energy
- mechanical energy
- a mechanism for the transfer or coupling of the energy with another medium for its transmittal
- a radiating surface.

This makes it easier to review noise control methods. If one or more of these factors are minimised or removed, the noise source will be unable to transmit energy.

**Minimising energy input**

Some sources of noise can be minimised by limiting the available energy that in turn causes vibration in equipment or surfaces. For instance, reducing the height of an object falling or avoiding impact. Figure 7.10 and Figure 7.11 show some examples of these techniques.

![Figure 7.9](image-url)  
**Figure 7.9** The effect of reflective surfaces near a sound source
Chapter 7: Noise and vibration

Using nails—noisy

Using screws—quiet

Steel sheet may be riveted—very noisy

or bolted—very quiet

Figure 7.10 Avoiding impact

Figure 7.11 Reducing fall height
Figure 7.12 Reducing panel area

Figure 7.13 Isolating plant from a reflective surface
Isolating vibrational sources from surfaces

This technique adopts the principle of reducing noise transmission between the source and reflective surface. By placing space between the vibrating source and the surface or reducing the surface area available for vibration, the noise can be reduced. It may also be as simple as removing a machine from the corner of a room where the walls and floors are highly reflective or placing the machine in a free field where the energy can dissipate evenly. Figure 7.12 and Figure 7.13 illustrate the application of this concept.

Vibrational damping

Damping of vibrational energy is a method of slowing the transmission of the vibration to other bodies. It involves stiffening the machine or plant to prevent additional vibration of the structural material.

CONTROLLING NOISE TRANSMISSION

If noise cannot be controlled at the source, then its ability to be transmitted should be minimised. This requires significant thought with respect to the possible ways that noise moves throughout the workplace. Consider a worker hitting an anvil in a workshop, with administration workers in an adjoining room. The obvious noise transmission occurs directly from the source to the receiver through the air. However, workers in other areas of the workplace may also be exposed to the noise indirectly through reflection from surfaces such as the ceiling and walls, other machines or structures. The third way that noise is transmitted is through a physical material such as a wall, floor or pipe. This transmission can be particularly disturbing for the occupants of buildings or rooms located adjacent to the noise source. This is known as structure-borne noise.

Sound absorption

We have already discussed the fact that the intensity of sound from a source not only will depend on its sound power level but also the propagation (including reflection and absorption). Surfaces that reflect sound will add to the sound levels and rooms with absorbing qualities will reduce it. If a workplace is particularly reverberant, the actual sound level will significantly increase. Several techniques are used to absorb sound, although these will depend on the frequency of noise emission.

In deciding on a sound-absorptive material, the characteristics of sound absorption must be understood. If a sound source is directed onto a surface, a certain amount will be reflected at the same angle as the incident waves. Otherwise, it can be absorbed or a partial effect will occur. The absorption coefficient is used to describe the reflectivity of a surface and is shown as Equation 7.15.

Equation 7.15

\[ \text{Absorption coefficient} = \frac{I_{\text{abs}}}{I_{\text{in}}} \]

Where:
- \( I_{\text{abs}} \) is sound intensity that is absorbed
- \( I_{\text{in}} \) is incident sound intensity

A perfect reflector has an absorption coefficient of 0, while a perfect noise-absorbing material would have an absorption coefficient of 1.0. This can be further expanded by using the 3 dB exchange rate to interpolate that an absorption coefficient of 0.5 would cause a reduction of 3 dB in the reflected noise. Absorption coefficients are given at a number of frequencies. Acoustic panels provide the best noise absorption, between 500 and 2000 Hz. Even air is an effective absorber of low-frequency sound (Figure 7.14).

Sound-absorbing materials can be incorporated into the design of a workplace or as
mobile devices. Sound booths or isolation booths for noisy processes are frequently lined with absorptive materials such as plaster and acoustic tiles. Heavy curtains are a portable technique that is most effective around 2000 to 4000 Hz. Other techniques might involve:

- **carpeting concrete floors**
- **placing vertical dividers between areas of an office**
- **using sound-absorbing baffles in the ceiling of a workplace.**

It should be noted that noise absorption techniques only marginally attenuate peak noise. Peak noise is the maximum instantaneous sound pressure over a very short time. Therefore, the sound-absorbing material must absorb the energy in this time and also return any reflected sound in an equally fast time.

### Noise insulation

Insulation refers to the ability of a medium to transmit noise, rather than to prevent reflection (which is the purpose of sound absorption).

Sound insulation characteristics are expressed as the transmission loss or the sound reduction index. A material that has good insulation properties is usually stiff and rigid, thus a large amount of energy is required to vibrate it and allow noise to be transmitted. The path of noise is reduced in this way.

Materials that are frequently used as noise insulators include concrete, steel and plaster or gypsum board.

Walls of buildings that require insulation characteristics frequently use these materials and some also incorporate a multi-layer approach with air cavities between layers. As a
general rule, the wider the air cavity the greater the noise insulation. Double-brick walls with a large air gap of about 100 mm can reduce transmission by around 80 dB at high frequencies and at least 40 dB at low frequencies. Windows can also be sound insulated by double or triple glazing. A resurgence of inner city living has increased the popularity of this practice. With double glazing, a gap of a few millimetres is left between the glass layers to act as insulation. However, such a small space provides minimal noise reduction. An air gap of around 100 mm between the glass layers is required to obtain a transmission loss of around 50 dB. Figure 7.15 shows some examples of noise insulation methods.

Partial barriers and screens are particularly useful in minimising noise transmission, especially at high frequencies. Since high-frequency sound has a short wavelength, it behaves in a highly directional way compared to low-frequency sound that tends to ‘bend’ around articles in its path.

**Administrative controls**

Some examples of administrative controls include:

- **minimising exposure duration through reduction in exposure time or job rotation**
- **organising for high-risk operations to be conducted out of hours or when few workers will be exposed**
- **re-organising the workplace to locate work activities or noisy equipment away from the main work area**
- **utilising the results from noise contour plans to mark zones where noise exposure may exceed regulatory or the organisation’s standards**
- **limiting or prohibiting certain high-risk tasks** (e.g. compressed air for cleaning is a high-frequency and high-intensity noise and this practice can also cause injection of air under the skin)
- **training workers on the effects of noise exposure, basic acoustics and how noise is measured and controlled**
- **audiometric testing.**
AUDIOMETRIC TESTING

Audiometry is a technique that measures hearing loss at a number of frequencies. An audiometer sends a pure-tone sound that corresponds with the threshold of hearing of a person whose hearing is not impaired to the ear of the listener. If there is no hearing loss, the listener will hear the tone.

However, where a loss does occur at a frequency, the listener will require the threshold level to be increased until they can hear the tone. A graph of frequency versus reduction is then constructed. Noise-induced hearing loss shows a characteristic dip at 4 kHz.

AS/NZS1269.4 gives specific procedures and requirements to conduct pure-tone audiometry. Generally, audiometers should comply with AS2586. Test tones are made at 500, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. The hearing levels of the person are tested over the range of at least 0 to 90 dB, although it is preferred that the range is extended from –10 to +100 dB.

The advantages associated with audiometry include:

- determining a person’s hearing threshold levels
- making people aware of their hearing loss
- identifying uncertainties in the use of hearing protection devices
- using the information for workers’ compensation and rehabilitation requirements.

The procedure for conducting audiometric testing begins by removing any article that might interfere with the proper placement of the earphones (e.g. glasses, hats, hearing aids and earrings). The earphones should be fitted by the tester to ensure correct seal and comfort. It is important that for the duration of the test the headphones are not touched by the worker being tested. Ensure that the earphone cup is sealed with the head. Hair should be moved away from between the ear canal and earphones.

Before the test is conducted, the worker should be briefed about the procedure and the expectations of them. AS/NZS1269.4 suggests that the briefing should include:

- the response task when a sound is heard (e.g. raising a finger or hand or pressing a button)
- an indication that the response needs to be as soon as possible after the tone is heard
- an indication that the sounds may be very faint
- that the ears will be tested individually, which ear is to be tested first and the pitch sequence
- an indication that the test can be terminated by the person if they wish.

There are two types of audiometers: manual and automatic recording audiometry. The type of audiometric testing device will govern the type of audiometry that is used.

For manual audiometry, the test procedure should begin at 1 kHz. The hearing level dial is set at 0 dB and is then gradually increased until the person responds. At this time, the hearing level is reduced by 10 dB, followed by a short burst of tone. If the person responds to this tone, it is reduced a further 10 dB and then the tone is emitted again. This is repeated until the person fails to respond. At the point where the person fails to respond, the hearing level dial is increased by 5 dB and tested again with three short tone bursts. If the person responds to only one of these three tone bursts, the hearing level dial is turned up another 5 dB and three more bursts are presented. If only two of the three bursts are responded to, the level of
the tone is decreased by 5 dB and three bursts
again presented.

The lowest level at which two out of the
three bursts are heard is taken as the person’s
threshold hearing level. The frequencies that are
taken in this sequence are 1000, 1500, 2000,
3000, 4000, 6000, 8000 and 500 Hz then 1000 Hz
is re-tested. The rechecked 1000 Hz should
agree with the initial test within ± 5 dB other-
wise the first test at 1000 Hz should be
discarded.

The results of audiometric testing should
be recorded using approved symbols of the
Australian Audiological Society.

Automatic recording audiometry is a lot
easier to conduct. Once recording has begun,
the test continues until both ears have been
tested once. The test is then repeated at one
or two of the first frequencies of the first ear. If
the results agree with the first testing, the
results can be kept. A deviation of more than
5 dB means the test should be repeated.

Once the testing has finished, the person
should be provided with a copy of their
audiometric assessment. The meaning of the
audiogram should be explained in a way that is
easy to understand. In some cases, further
audiometric testing is required to confirm a
threshold shift. The additional testing must be
conducted on another day and after at least
sixteen hours of quiet conditions. The cases
where further testing may be needed include:

- a shift in average threshold at 3000,
  4000 and 6000 Hz of 5 dB or more
- a shift in the mean threshold greater
  than or equal to 10 dB at 3000 and
  4000 Hz
- a change in the mean threshold of
  15 dB or greater at 6000 Hz
- a threshold shift of 15 dB or
greater at 500, 1000, 1500 or
2000 Hz
- a threshold shift greater than or
  equal to 20 dB at 8000 Hz.

These shifts would be compared with reference
audiometry and the person may be asked to
seek further medical opinion as to the cause of
the shift. From a risk management perspective,
a change in a worker’s hearing threshold is of
serious concern to the workplace. The
following steps should be taken to minimise the
risk of noise-induced hearing loss:

1. identify changes that may have contributed
to an increase in noise exposure.
2. Measure the current noise levels and
frequencies in the workplace.
3. Review the existing control methods,
including frequency and duration of
exposure.
4. Ascertain whether the attenuation of the
hearing protection device is suitable for the
actual noise exposure in the workplace.
5. Determine the integrity of the worker’s
hearing protection device for damage or
wear.
6. Ask the worker whether they have any
difficulty in using the supplied hearing
protection devices.
7. Check whether the worker actually uses the
hearing protection device correctly and
consistently.

**Calibration of the audiometer**

Similar to noise measuring devices, the
integrity of the audiometer must be tested
before use by calibrating the meter. First, a
tester with normal hearing conducts a listening
check prior to use.

This check aims to identify distortions and
other unwanted sounds from the audiometer
for at least three attenuator settings,
separated by at least 20 dB and for all
frequencies. A subjective calibration test
should be conducted at least once per week
but preferably each day. In this test, an
audiogram of a person with stable hearing is
taken at each test frequency and the results
compared with a known audiogram. If the
results differ by 10 or more dB at any frequency, the audiometer must be removed for service and a basic calibration. A basic calibration is conducted at a laboratory that is accredited to conduct such a test, and it must be performed at least once per year.

Since audiometry seeks to find reductions in hearing ability, it is vital that the test is conducted in a climate where background noise will not affect the final result. Before an area can be used to conduct audiometric testing, it must have ambient noise levels not exceeding the maximum levels in Appendix C of AS/NZS1269.4. An octave-band analysis is conducted in the area. This is the reason why some audiometric testing is conducted in a booth, where the integrity of the ambient noise levels can be guaranteed.

**HEARING PROTECTION DEVICES**

The use of personal protective equipment should be the final choice in minimising risk associated with exposure to noise. As with all forms of personal protective equipment, its effectiveness is governed by its application which in turn is affected by human behaviour. Fit and design of some hearing protective devices can affect their suitability for use. Some workers may have trouble inserting or wearing the equipment. There are also hygienic reasons for minimising the use of hearing protection devices. Earplugs are renowned for an increase in ear infections when inserted with dirty hands or in environments that may have a high humidity. The overall expense of hearing protection devices is rarely considered. The ongoing cost of purchasing disposable hearing protection devices and maintaining nondisposable devices must be factored into the overall budget for noise control.

There are four main types of hearing protection devices that are available:

- **earplugs**
- **earmuffs**
- **canal caps**
- **acoustic helmets.**

The principle of noise reduction using hearing protection devices is five-fold:

- completely cover the entire ear
- cover the entrance to the ear canal
- plug the ear canal
- neutralise noise before it reaches the ear by electronic methods
- cover the outer ear as well as a portion of the head.

**Earplugs**

Earplugs are inserted into the ear canal to restrict the transmission path of noise. They were traditionally made from wads of cotton or wool that were found to be effective when packed into the ear canal. Nowadays, earplugs are usually formed from expandable foam, soft silicone, rubber or plastic. There are several types of earplugs:

- **User-formed earplugs** — these are widely used in industry as they are commercially available in a range of colours and shapes. These earplugs are usually disposable and made from a compressible material that is squashed into a small cylindrical shape and inserted in the ear canal. As the earplug expands, it forms a seal with the walls of the ear canal.

- **Pre-moulded earplugs** — these are made from a variety of materials and in a number of sizes. The earplugs can be inserted directly into the ear canal without prior manipulation and are especially suited to applications where dust or dirt may affect the hygiene of the worker who is inserting the plug.
• **Custom-moulded earplugs** — these are custom-made (usually by audiologists) from a silicon or acrylic mould for the individual. They require a mould to be taken before the actual earplugs are formed and then are only suitable for the worker for which the earplugs were made.

• **Banded earplugs** — these earplugs are usually made from rubber, plastic or soft silicon and are connected to each other with a band.

The advantages of using earplugs as hearing protection devices are that they are easily worn with other forms of personal protective equipment such as safety glasses and safety helmets; some types are disposable; and they are relatively inexpensive. The disadvantages relate to problems with hygiene (infection in humid and wet conditions), the time taken for insertion and correct insertion.

**Earmuffs**

Earmuffs enclose the entire external ear with cups and soft cushions that form a seal with the head. The cups are lined with a noise absorptive material (e.g. foam) and are connected by a band that is worn over the head, below the chin or around the neck. The disadvantage of earmuffs is that they may not suit workers who are wearing other forms of personal protective equipment, such as helmets and glasses, or workers with long hair. To overcome problems associated with the fit of earmuffs with safety helmets, some earmuffs clip directly onto the helmet, preventing the need for the head-positioned spring band. Various other types of earmuffs are available that, to prevent entire isolation from audio stimulus, allow the radio or other sounds to be heard through the earmuffs.

**Canal caps**

Ear canal caps are usually tapered and attached to a spring headband. The plugs are pushed into the entrance of the ear canals, without actually entering them. The spring band holds the caps in place.

**Acoustic helmets**

Acoustic helmets are found infrequently in the industrial setting and their application is more common in aircraft industries. The principle of operation of the acoustic helmet is to prevent the transfer of acoustic energy both through the ear and by bone conduction.

**SELECTING HEARING PROTECTION DEVICES**

The choice of hearing protection devices will depend upon several factors, which include attenuation requirement, comfort, cost, fit and compatibility with work, the workplace and the wearer. The first issue, attenuation, is arguably the most important. Attenuation refers to the degree of noise reduction that is afforded to the listener. Depending upon the hearing protection device, it may protect only at certain frequencies. All hearing protectors must be type-tested and comply with the requirements of AS1270.

The values of attenuation given to the hearing protectors will be mean–minus–standard deviation ($x - \sigma^2$) values that are derived from laboratory attenuation measurements made in accordance with AS1270. While specified attenuation values are given, the ‘actual’ attenuation that workers may experience differs from the specified value because of interference by:

• **glasses**
• **long hair**
• other forms of protective equipment such as a safety helmet or respiratory protection
• age of the hearing protector
• condition of the hearing protector
• fit.

When selecting the appropriate hearing protection device, care should also be taken not to over-protect the worker. This leads to a sense of isolation from the work environment and conditions. It is important that communication can still occur when wearing hearing protection devices. Once used to wearing hearing protection, the perception of sound may actually be better than when not wearing the hearing protection devices. Earplugs and earmuffs can be worn in combination. This will increase the overall attenuation, although not in an additive factor. Information about combined effects is available from the manufacturer of the hearing protection device.

To select hearing protection devices, three methods can be used, according to AS/NZS1269.3:

• classification method — where the $L_{Aeq,8hr}$ is less than 110 dB(A), the noise is broadband and does not have significant low- or high-frequency components
• octave-band method — where the $L_{Aeq,8hr}$ is greater than or equal to 110 dB(A), the noise is narrow band with significant tonality or has significant high or low frequency components
• SLC80 procedure.

**Classification method**

This method is the easiest to use, since only the $L_{Aeq,8hr}$ is required. The $L_{Aeq,8hr}$ is simply compared with the hearing protector classification specified on the hearing protection device. It should be noted that this method only applies where the criterion eight-hour equivalent continuous A-weighted sound pressure level, $L(\text{crit})_{Aeq,8hr}$, is 85 dB(A). The $L(\text{crit})_{Aeq,8hr}$ is defined as the eight-hour equivalent continuous A-weighted sound pressure level above which the provision of hearing protectors is required by legislation or by the company’s noise policy.

**Octave-band method**

The octave-band method is used for determining the effectiveness of hearing protection devices where an octave-band analysis of noise has been conducted. This method is the most accurate, as it allows the various frequencies of the noise to be correlated with the efficiency of the hearing protectors at various frequencies. The procedure begins with the $L_{eq,T}$ measurements being recorded at 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. The next step to determine the effective level, $L_{eff}$, is to subtract the mean–minus–standard deviation octave-band attenuation of the hearing protector from the octave-band levels of the noise to which the worker was exposed. The mean–minus–standard deviation is a value that estimates the attenuation obtained or exceeded by 80 per cent of wearers. Where the noise has significant high- or low-frequency components AS/NZS1269.3 suggests that the 63 Hz and 16 kHz octave bands should be included in the calculations. For these, the mean–minus–standard deviation values of 125 Hz and 8 kHz octave bands respectively should be used. The values are then corrected for A-weighting and summated to give $L_{eq,T}$.

This procedure is shown as a series of steps in Example 7.8.
Example 7.8

An octave band analysis of a sound source showed the following results:

| Octave band centre frequency (Hz) | 125  | 250  | 500  | 1000 | 2000 | 4000 | 8000 |
| Equivalent SPL (Leq,T)            | 106  | 108  | 109  | 101  | 95   | 96   | 90   |

The hearing protection devices worn by the workers have the following attenuation:

| Octave band centre frequency (Hz) | 125  | 250  | 500  | 1000 | 2000 | 4000 | 8000 |
| Attenuation (mean – SD) (dB)      | 12   | 18   | 26   | 35   | 36   | 36   | 22   |

Step 1

For each octave, subtract the octave-band attenuation of the hearing protector from the actual noise exposure.

| Octave band centre frequency (Hz) | 125  | 250  | 500  | 1000 | 2000 | 4000 | 8000 |
| Equivalent SPL (Leq,T)            | 106  | 108  | 109  | 101  | 95   | 96   | 90   |
| Attenuation (mean – SD) (dB)      | 12   | 18   | 26   | 35   | 36   | 36   | 22   |
| Attenuated levels (dB)            | 94   | 90   | 83   | 66   | 59   | 60   | 68   |

Step 2

Add the A-weighting corrections. Where there are high and low frequencies and 63 Hz and 16 kHz octaves are measured, the A-weighted corrections are 26 dB and – 7 dB, respectively.

| Octave band centre frequency (Hz) | 125  | 250  | 500  | 1000 | 2000 | 4000 | 8000 |
| Attenuated levels (dB) from Step 1 | 94   | 90   | 83   | 66   | 59   | 60   | 68   |
| A-weighting correction (dB)       | –16  | –9   | 3    | 0    | +1   | +1   | –1   |
| A-weighted attenuated levels (dB(A)) | 78   | 81   | 80   | 66   | 60   | 61   | 67   |

Step 3

Combine the A-weighted attenuated levels from Step 2. Therefore the combined A-weighted effective sound pressure level is 85 dB(A).
SLC<sub>80</sub> method

The SLC<sub>80</sub> method for determining the effectiveness of the attenuation of hearing protection devices uses C-weighted sound pressure levels and the specified sound level conversion factor for 80 per cent of wearers (the SLC<sub>80</sub> value).

\[ L_{dB(A)} = L_{C,eq} - SLC_{80} \ (dB) \]

To calculate the sound pressure level at the ear, the SLC<sub>80</sub> is simply subtracted from the C-weighted sound pressure level. This is shown in Example 7.9.

**Example 7.9**

The C-weighted sound pressure level at the ear of a worker was measured to be 105 dB(C). If the SLC<sub>80</sub> value of the hearing protector that the worker is wearing is 22 dB, what is the effective noise exposure in dB(A)?

**Answer:**

\[ 105 \text{ dB(C)} - 22 \text{ dB} = 83 \text{ dB(A)} \]

VIBRATION

Exposure to vibration is usually synonymous with noise. The physics of vibration and noise are similar. Vibration can be explained in three forms: sinusoidal, periodic and random.

Sinusoidal motion occurs where an item is displaced from a neutral point to a positive and negative direction. The sinusoidal or harmonic wave used to describe noise (Figure 7.2) explains this. As the velocity of the wave increases and then decreases, the particle is in fact accelerating and decelerating. Therefore, the amplitude of acceleration is used to measure vibration, rather than the amplitude of pressure for noise exposure.

Periodic vibration is actually repeated sinusoidal vibrations, occurring simultaneously with their own amplitude and frequency.

Random vibration occurs where the vibration does not repeat itself; instead, it consists of a variety of frequencies at varying intensities. To determine the overall acceleration of random vibration each constituent vibration is analysed according to its frequencies and an average root mean square acceleration is obtained for each frequency.

Some sources of vibration include:

- pneumatic machinery or tools such as jackhammers and pneumatic chisels
- heavy vehicles such as long-haul trucks, tractors and underground mine vehicles
- vibrating floors from large processing plant
- motorcycle handlebars
- mowers, shearsers and gardening edge-clippers
- hand-held tools such as drills, sanders, polishers and grinders.

From these examples of vibration-generating sources, it can be seen that an important physic of vibration has not been discussed — the relationship between the item (its mass) and its stiffness. A source of sinusoidal vibration is the mass-spring system. In an idealised system, the mass can move only vertically, with the frequency that the system is moving at being dependent on its natural frequency. The natural frequency is the frequency that a system will vibrate at when excited randomly.

From an occupational hygiene perspective, if the damping of the vibrating system is effective enough, the natural frequency becomes zero. This means that after a disturbance the system returns to its equilibrium position without any oscillation.
Transmission of vibrational energy

Vibration can be transmitted in two ways:

- **force excitation** — transfer of force from the source (e.g. a machine) to a supporting structure (e.g. the floor)
- **motion excitation** — transfer of force from the supporting structure to the machine due to motion of the supporting structure.

The transmissibility of the force ($T_f$) is given as the ratio of the force transmitted ($F_t$) to the supporting structure from the exciting force ($F_e$). Examples of this type of transmission may be due to a vibrating generator connected to a building structure or a fan transmitting vibration through the supporting base. With motion excitation, the transmissibility of the motion ($T_m$) is given by the ratio of transmitted motion ($X_t$) to the excitation motion ($X_e$). These ratios are shown as Equation 7.16 and Equation 7.17, respectively.

**Equation 7.16**

$$T_f = \frac{F_t}{F_e}$$

**Equation 7.17**

$$T_m = \frac{X_t}{X_e}$$

**HEALTH EFFECTS OF EXPOSURE TO VIBRATION**

The health effects of exposure to vibration can be categorised according to the intensity and frequency of the vibration. The intensity of vibration is measured as the amplitude of acceleration. With high-intensity vibration levels, the body organs are battered at relatively low frequencies (e.g. heavy vehicles driving over uneven and bumpy ground).

Vibrational intensities at the lower scale are suspected of causing fatigue of the back, leading to degenerative changes. Whole-body vibration is the term used to describe this form of vibration. In addition to the degenerative effects on the spine, whole-body vibration can also affect vision, since the image presented to the retina is not stable. Whole body vibration will occur when the vibrational energy is between 1 Hz and 80 Hz. The body has a whole-body resonance, around 5 Hz for vertical vibration. When seated, the vibrational resonance occurs at two frequencies, 5 Hz and about 10–12 Hz. The major effects can be categorised as comfort-related effects, health-related effects and performance-related effects.

Frequency-dependent effects occur especially at high frequencies; for instance, when using powered hand tools such as drills, grinders, pneumatic hammers, chisels and Sanders. The vibration damages the blood and nervous supply to the fingers and hands, leading to a temporary loss of muscle control and white ‘blanching’ of the fingers. These symptoms are known as vibration white finger (VWF) or Raynaud’s disease. These symptoms are further exacerbated by cold and wet conditions. Other soft-tissue injury symptoms such as inflammation of the nerve, muscles or connective tissue are also associated with exposure to vibration. The bones of the hand or arm are also prone to damage.

Exposure to vibration also has an effect on comfort. For instance, frequencies of 0.1–0.63 Hz are associated with motion sickness. Vibration can also affect the ability to perform tasks such as writing, reading and eating.

**MEASURING VIBRATION**

Vibration should be measured in the direction of an orthogonal coordinate system (Figure 7.16) that has its origin at the heart. Measurements should also be made at the
point or area through which the vibration is transmitted through the body and is given as the root mean square acceleration and expressed in m.s\(^{-2}\).

The acceleration is measured using a transducer or pick-up that is located at the source of the vibration. The most common type of transducer is a piezoelectric accelerometer, where two piezoelectric discs produce a voltage on their surfaces due to the mechanical strain on the discs. An amplifier enlarges the signal, which is sent through an analyser to measure the vibration in a specific frequency range and then changed to a device calibrated in vibrational units. In most situations, the analyser consists of an amplifier and detection device that can measure a characteristic of vibration such as acceleration, peak or root mean square. A precision sound level meter that is configured with a vibration transducer is the most common analyser that is used.

For whole-body vibration, the measurements are made using a tri-axial seat accelerometer that is usually moulded into a rubber pad. This is placed on the point where the vibration is generated and/or transmitted.

For hand–arm vibration, the accelerometer is moulded into a ‘ring’ shape and is slipped on the finger. The vibration is also measured in three axes — x, y and z.

**Whole-body vibration measurement**

The reference for evaluating whole-body vibration exposure is AS2670.1. The standard prescribes three types of exposure standards:

- **exposure limit** — a limit for ensuring health and safety
- **fatigue-decreased proficiency boundary** — for maintaining work efficiency (especially tasks where time can affect performance, e.g. driving vehicles)
- **reduced comfort boundary** — to preserve comfort (particularly for tasks where comfort can affect activities such as eating, reading and writing).

For occupational hygienists, the most frequently used exposure standard is the exposure limit. The exposure limit is a combination of the frequency and duration of exposure. It should be the maximum value that

![Figure 7.16 The orthogonal coordinate system](image-url)
is not exceeded at any time unless special precautions and controls are taken.

The fatigue-decreased proficiency boundary is a level beyond which a significant risk to working efficiency may occur. It is expressed as a function of frequency and exposure time for either longitudinal (a<sub>z</sub>) or transverse acceleration (a<sub>y</sub> and a<sub>x</sub>).

Exposure graphs (from AS2670.1) are read by deciding on the exposure standard that is to be used and then comparing the measured acceleration (m.s<sup>–2</sup>) at certain frequencies to determine the allowed exposure time. From these graphs, the acceleration levels of the exposure limit standard are actually the fatigue-decreased proficiency boundary multiplied by a factor of two (or 6 dB higher). The reduced comfort boundary is obtained by dividing the fatigue-decreased proficiency by 3.15 (or reducing it by 10 dB).

The standard focuses on four criteria: intensity, frequency, direction of vibration and duration of exposure. The intensity refers to the magnitude or acceleration of the vibration. Its frequency will impact on the body organs that are affected by exposure. The direction of vibration is measured in either the x, y or z axes. Duration of exposure will impact on the risk of adverse health effects to workers.

From the exposure standards, it can be seen that the body is most vulnerable to frequencies of 4–8 Hz for longitudinal vibration. For transverse vibration the sensitive frequencies are around 1–2 Hz.

**Hand–arm vibration measurement**

Hand-arm, or segmental, vibration occurs where a section of the body is exposed to the vibrating source and the remainder of the body lies in a generally stable and stationary area.

Since the area of effect is quite small, the measurement devices must be conducive to being placed on this area while still maintaining adequate sensitivity to record the acceleration. The technique for monitoring hand–arm vibration is similar to that of whole-body vibration. The main difference lies in the use of two orthogonal coordinate systems to describe the direction of the vibration: the basicentre and biodynamic systems.

The basicentre system is defined by considering the location and direction of the tool or equipment. The biodynamic system takes its reference from the knuckle of the third finger of the hand. As the tool is being used, the accelerometer is attached either to the tool or on the surface between the palm of the hand and the tool. AS2763 is the standard that provides guidance for measuring and assessing hand–arm vibration for an exposure period of four hours. The three axes are monitored for their accelerations and the largest of the weighted accelerations is then chosen. AS2763 includes graphs which indicate the probability that vibration-induced white finger syndrome will occur at particular accelerations (measured as rms).

It is important to remember that the graph is given for an equivalent rms acceleration value over an exposure period of four hours. The graph then prescribes the percentage of people who are exposed at this weighted acceleration and the time before vibration-induced white finger exposure will occur.

In some cases, exposure to vibration may not be the same. For instance, different tools with different accelerations may be used. In this case, the equivalent frequency-weighted acceleration can be determined by considering the duration of exposure and acceleration. This is showed in Example 7.10.

**Example 7.10**

A worker uses the following tools with frequency-weighted accelerations and durations of exposure as shown below:
- a grinder for 3 hours at 10 m.s<sup>–2</sup>
- a sander for 2 hours at 13 m.s<sup>–2</sup>
- a drill for 2 hours at 9 m.s<sup>–2</sup>
What is the equivalent frequency-weighted acceleration?
Answer:
\[ a_{w,eq,T} = \frac{(10 \times 3) + (13 \times 2) + (9 \times 2)}{7} = 10.6 \text{ m.s}^{-2} \]

Since the graph from AS2763 is expressed as an acceleration value for a daily period of four hours, it may be necessary to adjust the frequency-weighted acceleration to this period. Equation 7.18 shows how this can be conducted.

**Equation 7.18**
\[ a_{w,eq,4hr} = a_{w,eq,T} \times \frac{T}{4} \]

Example 7.11 converts exposure from seven hours to four hours to compare with the guidelines.

**Example 7.11**
Convert \( a_{w,eq,7hr} \) of 10.6 m.s\(^{-2}\) to \( a_{w,eq,4hr} \)
Answer:
\[ a_{w,eq,4hr} = 10.6 \times \frac{7}{4} = 14 \text{ m.s}^{-2} \]

**CONTROLLING VIBRATION EXPOSURE**

The techniques used for minimising exposure to vibration follow similar principles to that of noise exposure. The hierarchy of control can also be adopted, although practicability may affect the application of certain principles of the hierarchy. For whole-body vibration, the source of vibration can be minimised by increasing the stiffness of the source to reduce the resonance. Other methods of source alteration include:

- re-balancing unbalanced fans or rotating drums
- maintaining components of large machinery to minimise vibration generation
- altering the energy requirements of the process that can generate vibration.

Otherwise, isolation of the vibration source or restricting its transmission can be effective control mechanisms. Isolating techniques can only be effectively applied if the ratio of disturbing frequency to natural frequency is known. If the ratio is greater than \( \sqrt{2} \), isolation is feasible. For ratios less than \( \sqrt{2} \), damping should be used. Some examples of isolation methods include:

- **anti-vibration mountings (AVM)** — that isolate the vibration source from its supporting structure to reduce transmission
- **inertia blocks** — such as heavy concrete or steel, to increase the mass and therefore lower the vibration amplitude.

**Anti-vibration mountings**

There are several forms of anti-vibration mountings (AVM), which are useful in isolating vibration. Springs, rubber mats, cork isolators and insulation pads all adopt the same philosophy of providing a barrier between the vibrating source and the floor or surface to which it is mounted. The magnitude of isolation will depend upon the amount of compression that the material can generate.

The most effective form of AVM are springs. Some typical applications of these in industry include:

- mounting heavy vehicle drivers’ seats on a suspension system
- placing laboratory benches with sensitive scales on spring isolators
- mounting the vibrating screens in
coal preparation plants mounted with springs to reduce overall vibration transmission throughout the plant.

**Inertia blocks**

Inertia blocks increase the mass of the vibrating source in order to decrease the vibration amplitude and minimise rocking. The only limitation with inertia blocks is that they must also be accompanied with isolators. They are particularly effective for a number of vibration plants that must be continually supported.

**Damping**

Where the ratio of disturbing frequency to natural frequency is less than $\sqrt{2}$, damping is recommended. Damping is particularly efficient where the generated vibration levels are similar to the resonating frequencies. This allows the mechanical energy from the vibrating source to be converted to thermal energy. Some examples of damping include:

- lining pipes and chutes with rubber,
- using a combination of hardwood and fibreboard for wall construction
- a combination of steel plating and a thick damping layer to enclose a vibrating plant in a large workshop.

**Segmental vibration control**

The main characteristic of segmental vibration that contributes to its hazardous nature is its proximity from the source to a particular area of the body. To minimise risk of vibration white finger, vibration transmission can be halted either at the source or at the path. The two main techniques used are damping in tools and damping gloves.

Anti-vibration tools place damping material between the tool housing and the hand or inside the tool to reduce the produced vibration. The materials are usually rubber or other visco-elastic materials that dampen the high-frequency components of the vibration.

Since segmental vibration can cause degeneration of the vascular, muscular and nervous tissue of the hand and arm, another method of limiting exposure is to reduce the transmission through the tool to the body. Anti-vibration gloves are useful in this regard but can be cumbersome and reduce the tactile response and grip strength. They are also aimed to protect against high frequencies. The advantage of the gloves is that they can help keep the hands warm and prevent cuts or other skin abrasion.

**Administrative controls to minimise vibration exposure**

These controls are similar to those suggested for noise exposure and include:

- pre-employment medicals to assess workers who may be susceptible to the effects of exposure to whole-body and segmental vibration
- maintenance of tools and adopting the principle of purchasing tools with minimal vibration
- work–rest regimes to minimise exposure to vibration.

Training about the risk associated with exposure to vibration should also be provided, including work practices such as:

- keep the hands warm and do not allow them to become wet and cold
- do not smoke (a vasoconstrictor) when using vibrating hand tools
- use supplied personal protective equipment such as anti-vibration gloves with full fingers
- reduce exposure time associated with the vibration source where
possible by using only when necessary
• grasp the tool lightly enough to maintain control but not too lightly

• at the signs of numbness, tingling or white or blue fingers, seek medical advice as soon as possible.

SUMMARY

As occupational hygiene hazards, noise and vibration are among the most commonly faced in Australian workplaces. Noise is a term used to describe our interpretation of sound. However, excessive exposure may lead to physiological and psychological effects.

Exposure to vibration through the body or the hands and arms can also result in adverse health effects. This chapter has described the physics of noise and vibration, the health effects and methods for monitoring and interpreting the risk associated with exposure to these hazards.

BIBLIOGRAPHY AND FURTHER READING


Standards Association of Australia 1990, *AS2670.3: 1990 Evaluation of Human Exposure to Whole-body Vibration — Evaluation of Exposure to Whole Body Z-axis Vertical Vibration in the Frequency Range 0.1 to 0.63 Hz*, Standards Australia, Homebush


In Australia, exposure to the extremes of heat and cold occurs more often than you may realise. With such an expansive land area that extends from the tropics in the north, deserts in the centre and snow-covered mountains in the south, heat and cold are real occupational hygiene issues.

The body has its own thermoregulatory system to respond to such extremes but in some cases this is inadequate. Mines, foundries, outdoor work and laundries are typical sources of excessive heat, which can also be combined with high relative humidities. Cold exposure may occur for workers in the meat processing industry, cold storage warehouses or while working outdoors during the winter months in southern states.

This chapter describes the body’s mechanism for regulating heat, thermoregulation; health effects from exposure to extremes of heat; and environmental and physiological methods for assessing the risk of heat-induced illness. A variety of controls are also described that can be adopted in most workplaces.

**THERMOREGULATION: MAINTAINING THE BODY’S EQUILIBRIUM**

The human body must maintain a constant internal environment, even when external conditions alter. This equilibrium is called homeostasis. Homeostatic balance occurs where receptors monitor the environment and respond to these changes to balance the internal workings of the body within a small window or range.

However, the body has only a limited capacity to adjust to extremes of temperature and humidity. An imposed heat stress from the environment will cause a resulting strain on the body. This typically produces physiological reactions such as increased skin temperature, sweat production, increased heart rate and higher core temperature.

Low levels of heat stress cause discomfort because the body must adjust to cope with the extra heat load while higher levels can lead to serious health problems.

The human body’s thermal regulation system is controlled principally by the hypothalamus, which contains neurones that are sensitive to changes in arterial blood temperature. The hypothalamus integrates the information from these various sensory nerves and regulates heat loss from the body. The thermoregulatory system of the human body tries to keep a heat balance in which there is no net loss or storage of heat. This can be described by the heat balance equation (Equation 8.1) that is shown on the following page.
Equation 8.1

\[ S = M - W - R - C - E - C_{res} - E_{res} - K \]

Where:
- \( S \) is heat storage (W.m\(^{-2}\))
- \( M \) is metabolic rate (W.m\(^{-2}\))
- \( W \) is external work rate (W.m\(^{-2}\))
- \( R \) is the heat rate loss by radiation (W.m\(^{-2}\))
- \( C \) is the heat rate loss by convection (W.m\(^{-2}\))
- \( E \) is the heat rate loss by evaporation (W.m\(^{-2}\))
- \( C_{res} \) is the dry heat rate loss by respiration (W.m\(^{-2}\))
- \( E_{res} \) is the latent heat rate loss by respiration (W.m\(^{-2}\))
- \( K \) is the heat loss rate by conduction (W.m\(^{-2}\))

For most people, the core body temperature in organs such as the brain, heart and the intestinal canal should be maintained around 37°C. This may vary from individual to individual, although it is generally accepted that deep body temperature should not fall less than 36°C or rise to more than 38°C. It is clear then that the body’s core temperature must be kept to within quite narrow limits. A temperature increase of about 5°C is likely to lead to death, as is a reduction by only 3–4°C. Even small departures from this band can lead to decrements in both motor and cognitive performance. There are a number of mechanisms for minimising heat gain or loss: conduction, convection, radiation and evaporation.

Conduction

The transfer of heat by direct contact with a solid, fluid or gas (including air) is called conduction. Heat exchange between the body and the environment frequently occurs in this manner. For instance, touching the base of a clothes press or a hot floor surface. The skin is also a good conductor, where the blood vessels close to the surface dilate and allow their heat to be transferred to the air.

Convection

Convection is the transfer of heat by currents of air. This is the principle behind heating, ventilation and air conditioning (HVAC) systems. Since heat is transferred or lost from the body through the air, the skin temperature has an important impact on temperature regulation. If the air temperature is above 35°C, the body will gain heat from the air. If below 35°C, there will be a net loss of heat through the skin.

Radiation

Radiation is the process by which the body gains heat from surrounding hot objects and loses heat to cold objects without actually touching them. Some sources of radiant heat include the sun, a fire or boiler. No radiant heat gain or loss occurs when the temperature of surrounding objects is about 35°C.

Evaporation

Heat can be dissipated by the evaporation of sweat. The body’s second line of defence against heat stress is increased sweating. Perspiration is heated by the skin and is transformed into water vapour, which is then carried away from the skin by currents of air.

The Effects of Exposure to Excessive Heat

When the body is unable to adequately regulate core body temperature at an optimal level, heat illness may result. Working in a hot environment puts the body (and the cardiovascular system) in a difficult situation.
Ultimately, the body must ensure working muscles have an adequate supply of blood but it must also redistribute blood to the skin to facilitate heat exchange through conduction. To do this, a disproportionate amount of blood is shunted to the skin for heat exchange. The consequence of this routing of blood is a reduction in the volume of blood returning to the heart, thereby decreasing the amount of blood pumped per heartbeat (stroke volume).

In hot conditions heat loss is increased first by vasodilation which increases the flow of blood to the skin and raises skin temperature. If this is insufficient, body temperature will rise further and sweating begins to increase heat loss by evaporation. Repeated exposure to heat leads to modified responses in the sweating mechanism and cardiovascular system. This is known as heat acclimatisation.

Where the environment is both hot and humid (the air is saturated with water vapour), such as underground mines and laundries, excessive fluid loss can occur over a work shift. This is chiefly due to evaporative heat loss achieved by sweating and inadequate hydration. Depending upon the severity of fluid loss, the total blood volumes can decrease to such a level where stroke volume is reduced. The major effects of exposure to heat stress are prickly heat rash, heat cramps, heat oedema, heat syncope, heat exhaustion, heat stroke and hyperpyrexia.

**Prickly heat rash**

Heat rashes exhibit as red spots on the skin that cause a prickling sensation during heat exposure.

**Heat cramps**

Heat cramps are often the first indicator of a heat-related problem. Symptoms are sharp and painful spasms in the muscles that are being stressed. Deep body core temperature is still within the normal range of approximately 36°C to 38°C. Heat cramps usually occur in unacclimatised workers who have replenished water lost through sweating but who have not replaced salt at the same time.

**Heat oedema**

One of the milder afflictions caused by exposure to heat is called heat oedema. This condition causes swelling which is most noticeable around the ankles and generally occurs among workers who are not acclimatised to working in hot conditions.

**Heat syncope**

Heat syncope (heat-induced giddiness and fainting) is caused by the loss of body fluids through sweating and by lowered blood pressure due to pooling of blood in the legs while working in a standing position.

**Heat exhaustion**

Heat exhaustion or prostration is also caused by salt depletion and is characterised by excessive sweating but with cold, pale and clammy skin. Dizziness, blurred vision and unconsciousness may accompany a rapid but weak pulse. Nausea, heat cramps and rapid shallow panting may also be present.

**Heat stroke and hyperpyrexia**

The most serious heat illnesses are heat stroke and hyperpyrexia. These are caused by prolonged work in extremely hot environments. Symptoms of heat stroke include dry, hot skin. This is due to the failure of sweating. Body temperature often exceeds 41°C and complete or partial loss of consciousness occurs. The signs of heat hyperpyrexia are similar except that the skin remains moist. Heat stroke and heat hyperpyrexia can be fatal and require prompt medical attention.
Assessment of heat stress can be conducted by measuring its effect on the human body using physiological monitoring. This involves testing an individual worker rather than the environment in which they are working. The advantages of this type of exposure assessment include:

- the ability to track an individual’s response to heat
- avoidance of generalisations about fitness, acclimatisation and hydration that are assumed with environmental monitoring.

The most efficient and accurate method of evaluating if a worker is being placed at risk of a heat-related illness is to take direct measurements of heart rate, core body temperature, skin temperature and possibly sweat loss.

Heart rate

Heart rate is influenced both by an increased metabolic rate and heat load. The increased cardiac output required by working muscles and the added circulatory strain imposed by heat exposure causes a corresponding increase in heart rate. Heart rate can be monitored either through direct palpation or more easily with a sensing device such as the Polar® heart rate monitor (Figure 8.1).

Case study 8.1

The central and western regions of Queensland are renowned for unrelenting high ambient temperatures around 40°C during summer months. Some maintenance operations at open-cut coalmines require workers to crawl into confined spaces with little ventilation. A boilermaker was repairing the bucket of a dragline in these conditions and suffered a heat-induced illness as a result of the radiant heat, protective clothing that had to be worn and ambient conditions.

The worker had recently returned from extended leave in a much cooler location and was not acclimatised to the working conditions.

PHYSIOLOGICAL MONITORING OF EXPOSURE TO HEAT
These devices consist of a transmitter, which is worn around the chest, and a wrist receiver. The device is frequently used by athletes but is also useful to track a worker’s heart rate and relate this to stresses caused by exposure to heat.

Since heart rate is affected not only by heat but also by metabolic work, it is sometimes difficult to differentiate an increase in heart rate exclusively from heat. In Australia there is no standard heart rate that is recommended for work. An increase in heart rate can be due to a number of individual factors, including fitness, illness or anxiety. Minard (1973) suggests a mean heart rate of 110 beats per minute (b.min⁻¹) over an eight-hour shift is a reasonable limit for work involving heat exposures. The ACGIH have provided heart rate guidelines relating to tasks where the wet bulb globe temperature (WBGT) threshold limit values are exceeded or if water–vapour impermeable clothing is worn. In such situations, it suggests that work should discontinue if a sustained heart rate is more than 160 b.min⁻¹ for those under 35 years of age or 140 b.min⁻¹ for those aged 35 years or older.

**Core body temperature**

One of the most direct outcomes of excessive exposure to heat is a rise in core body temperature. A variety of techniques exist for monitoring deep body core temperature but only a few are practical for use in an industrial setting. The more practical measures include rectal, oral, skin and aural (ear) temperature.

Rectal temperatures up to 38°C or slightly higher are usually viewed as acceptable or safe, while temperatures around 39°C have been described as undesirable or unsafe. Physiological monitoring of core body temperature overcomes the inherent problems of extrapolating environmental temperature readings and metabolic heat production estimates. The ACGIH advises that workers should not be allowed to continue their work when their deep body temperature exceeds 38°C. However, additional care must be taken with pregnant workers. If a pregnant worker’s core temperature exceeds 39°C for extended periods during the first trimester, the unborn foetus is at increased risk of malformation. Core body temperatures above 38°C have also been reported to cause temporary infertility in both males and females.

**Skin temperature**

One mechanism of body temperature regulation is to vary the amount of blood flowing to the skin. This changes the skin temperature, and hence changes the rate at which heat is lost or gained by radiation and convection. The mean skin temperature of a person feeling comfortable in an environment is around 33°C. Skin temperatures over the trunk will usually be 3–4°C higher than over the limbs.

Where the environmental surroundings are warmer than the skin, heat cannot be lost through radiation and convection; instead, the body will gain heat from its surroundings. In this case, sweating is a very effective manner to prevent overheating.

One method of monitoring skin temperature is to use a digital thermometer that is placed over various locations on the body.

**Sweat loss**

The most important avenue of heat loss during exercise or work is the evaporation of sweat from the surface of the skin. Situations that limit this process such as high relative humidity reduce thermal tolerance and increase the susceptibility to thermal injury. One technique to measure electrolyte loss is
the use of an electronic device that looks similar to a wristwatch. It collects a sample of sweat. The accumulated sample is then evacuated for electrolyte analysis.

Other methods for assessing fluid loss are to consider the overall weight loss during a shift by firstly weighing the worker before work (preferably nude) and again at the end of the shift. The weight of food and drink consumed during the shift is closely monitored to provide an indication of overall fluid loss during the shift. Gross fluid change represents the change in hydration status resulting from the metabolic work rate and ambient environmental conditions. It can be calculated using Equation 8.2.

**Equation 8.2**

\[
GFC = BM_{\text{PST}} - BM_{\text{PRE}} - F_i - FL_i
\]

Where:

- GFC is gross fluid loss
- BM_{\text{PST}} is body mass post-shift
- BM_{\text{PRE}} is body mass pre-shift
- F_i is food intake
- FL_i = fluid intake

The net fluid change represents the overall degree of dehydration experienced over the course of a shift, taking into consideration the fluid intake of the worker. To determine this, Equation 8.2 is used minus FL_i.

**THE EFFECT OF METABOLIC WORK RATE**

Metabolic work rate refers to the work that is performed by the muscles during respiration. It is denoted by the symbol M (Equation 8.1) and has been determined for several types of jobs and magnitude of work.

Metabolic work rate will contribute to the overall heat loss or gain of the body; therefore, the imposed heat from the environment is not the only parameter to consider. Muscular work is associated with an increase in the body’s metabolic rate. This occurs because of the working muscles’ increased demand for oxygen and nutrients.

With an increase in metabolic rate, however, comes an increase in the amount of heat produced. This is a result of the largely inefficient process of converting energy into external work (termed the mechanical efficiency). Generally, the mechanical efficiency of muscular work is between 0 per cent and 50 per cent (Astrand & Rodahl 1986), with most forms of exercise exhibiting efficiencies in the range of 20–25 per cent (Bray et al., 1994). This means that 50–75 per cent of the energy expended to create movement is released into the body as heat. A significant portion of this heat load must be dissipated to the external environment, otherwise the body will retain and accumulate heat, leading possibly to an abnormal increase in core temperature, followed potentially by the development of heat stress.

**ENVIRONMENTAL MONITORING OF EXPOSURE TO HEAT**

The least intrusive way to monitor a worker’s exposure to excessive heat is to measure the environment. Environmental factors influencing heat exchange include the air temperature, humidity, airflow and the temperature of surrounding surfaces. Therefore, the four basic parameters that need to be considered are:

- **air temperature** (dry bulb and wet bulb)
- **relative humidity** (the partial pressure of water vapour in the air expressed as a percentage of saturation vapour pressure which varies with temperature)
• mean radiant temperature (the average temperature emitted from a radiant heat source)
• air velocity (the air velocity is related to evaporative and convective methods of heat loss).

**Dry bulb temperature**

The dry bulb (DB) air temperature is measured by simply using a mercury-in-glass or alcohol-in-glass thermometer. When measuring room temperature, it should be located at approximately head height (1.5–1.8 metres from the ground). A possible confounder of dry bulb temperature results is the effect of radiation. If the thermometer is exposed to a radiant heat source, such as a fire or boiler, it should be shielded by either silvering the outside of the glass bulb or enclosing it in aluminium foil.

**Wet bulb temperature**

Wet bulb (WB) temperature is obtained from a thermometer that has been covered in a wetted gauze or cloth. It is then subjected to a forced air velocity of 2 m.s\(^{-1}\). It should also be shielded against the effects of radiation. An example of a device that measures wet bulb temperature is the sling psychrometer or whirling hydrometer (Figure 8.2). The device consists of both a dry bulb and wet bulb thermometer and is used to calculate the relative humidity.

**Natural wet bulb temperature**

The philosophy behind natural wet bulb (NWB) temperature is similar to that of the wet bulb temperature, except that air is not forced over the wetted wick. The natural wet bulb temperature is used to calculate the wet bulb
globe temperature, an environmental heat stress index. There are two methods that can be used to convert between wet bulb and natural wet bulb temperatures. These are shown in Equation 8.3 and Equation 8.4.

**Equation 8.3**

\[
WB = NWB - 0.5 - 0.13 (GT - DB) \\
\text{for } v > 1 \text{ m.s}^{-1} \\
WB = NWB - 1.5 - 0.13 (GT - DB) \\
\text{for } v < 1 \text{ m.s}^{-1}
\]

Source: Kamon & Ryan (1981)

**Equation 8.4**

\[
NWB - WB = [0.16 (GT - DB) + 0.8 (560 - 2RH - 5DB0] - 0.8 \text{ for } v > 0.15 \text{ m.s}^{-1}
\]

Source: Malchaire (1976)

**Globe temperature**

Globe temperature (GT) is determined from an ordinary glass thermometer that is inserted into the centre of a copper sphere with a diameter of 15 cm. The ball is painted in matt black paint so that the exposed thermometer bulb measures both the air temperature and influences from radiation. If there is no effect from radiant temperature, then GT will equal DB temperature.

**Radiant temperature**

Radiant temperature (RT) is rarely used for occupational hygiene purposes since it is merely the electromagnetic radiation from a source. However, it can be calculated using Equation 8.5, from the globe temperature, air velocity and dry bulb temperature.

**Equation 8.5**

\[
RT = [(GT + 273)^4 + 2.47 \times 10^8 v^{0.5}]^{1/25} - 273
\]

Where:

GT is globe temperature (Kelvin)

v is air velocity (m.s\(^{-1}\))

DB is dry bulb or air temperature (Kelvin)

**Air velocity**

Air velocity or airspeed (v) is measured in m.s\(^{-1}\). There are several methods of measuring air velocity including a hot-wire anemometer, vane anemometer and Pitot tube. These are described in Chapter 13.

To determine the air velocity associated with heat, the best device is the Kata thermometer. Its advantages are that it responds to many directions of airflow and it measures air velocity of a period of time. The Kata thermometer (Figure 8.3) consists of a silvered bulb that has two levels marked on the thermometer. It is immersed into hot liquid until the liquid passes to the top timing mark, then quickly removed and the bulb dried. The time taken for the liquid to pass between the two marks is recorded and the velocity
determined by considering the cooling factor of the individual Kata thermometer.

**Relative humidity**

Relative humidity (RH) refers to the saturation of air by water vapour and is expressed as a percentage. For highly saturated air the humidity is high (close to 100 per cent). In dry conditions the relative humidity is low. Relative humidity can be measured by using a sling psychrometer. Its operation is relatively simple. The sling psychrometer consists of two thermometers, a wet bulb and dry bulb. A ‘wick’ or ‘sock’ covers one of the thermometers (the ‘wet’ bulb) and should be thoroughly wetted using distilled water prior to taking any measurements. This will involve filling the water reservoir at the end of the psychrometer and may also involve manually wetting the wick. Care should be taken not to contaminate the wick with dirty fingers or water that is not de-ionised.

The handle is then unclipped and the psychrometer is swung for at least 20–30 seconds. This will allow an air movement to pass over the wet bulb thermometer and initiate evaporation of water from the wick. After 20–30 seconds, the wet bulb temperature is read first (then the dry bulb temperature). These values are noted and the measurements repeated three times. Optimally, the repeated measurements should be within around 1°C of each other.

Using a psychrometric chart (Figure 8.4), the relative humidity in the measured environment can be determined. Firstly, the depression of wet bulb temperature is calculated (this is simply the wet bulb temperature subtracted from the dry bulb
temperature) and this depression found on one axis of the table. Secondly, the dry bulb temperature (listed on the other axis of the table) is used to directly read the relative humidity level.

**HEAT STRESS INDICES**

A heat stress index is a single number that integrates the effects of basic parameters in any thermal environment. It aims to correlate the number with the thermal strain experienced by an exposed person. At this point, it is important to distinguish between two terms: heat stress and heat strain. Heat stress describes the total heat load on the body from all sources. Heat strain relates to the physiological response to the imposed stress.

The aim of heat stress indices is to provide an accurate prediction of workers’ physiological state at any time of the exposure. This in turn will allow assessment of the permissible duration of exposure and the duration of rest breaks. Even though development of an index has continued for almost a century, it has proved difficult to derive a single-figure heat stress index which is both an accurate indicator of risk and universally applicable.

There is probably more than a dozen heat stress indices available for use in studying the relationship between heat stress and heat strain. The main indexes that can be used to manage the risk of heat stress are the:

- **effective temperature (ET) or corrected effective temperature (CET)**
- **predicted 4-hour sweat rate (P4SR)**
- **wet bulb globe temperature**
- **heat stress index (HSI)**
- **required sweat rate.**

The P4SR, WBGT, ET and CET are empirical indices. This means that they were developed after considering the physiological responses of people. The HSI was modelled on the heat balance equation. More recently, an analytical index called the required sweat rate has been developed. This has been adopted by the International Standards Organisation as ISO7933, as a method to evaluate and interpret the thermal stress experienced by a subject in a hot environment. The standard does not predict the physiological response of individual workers but only considers the standard subjects in good health and fit for the work they perform. The calculations of required sweat rate are complicated and usually performed by computer.

**Effective temperature index and corrected effective temperature index**

Houghton and Yaglou (1923) devised the effective temperature index as a comfort scale. It combines the effects of air temperature, humidity and air movement into a single value (ET). The limitation of effective temperature is that it was not devised to make an allowance for radiant heat. It was later modified to form the corrected effective temperature index. This index uses a globe thermometer reading instead of the air temperature reading but is otherwise similar to the ET index. The chart used for determining both the ET and CET indices is shown in Figure 8.5.

**Predicted 4-hour sweat rate**

The predicted 4-hour sweat rate index measures sweat rate as a function of climate stress. It uses a nomogram (Figure 8.6) to predict the quantity of sweat given off over a four-hour period. The P4SR is one of the few indices which takes into account all of the environmental factors in addition to metabolic rate and clothing.
Figure 8.5 Corrected effective and effective temperature
The index is expressed in terms of the average amount of sweat produced by a group of healthy heat-acclimatised young European men in a four-hour exposure to the conditions. A disadvantage is that it covers only a moderate range of physical activity.

**Wet bulb globe temperature index**

The wet bulb globe temperature index may be utilised to predict a worker’s physiological state at any time of exposure to heat. It was...
developed in a United States investigation into heat casualties during military training and is currently recommended by the ACGIH. It is actually an environmental measurement from which the potential for heat stress is inferred, by considering:

- globe temperature
- dry bulb temperature
- the temperature of a naturally ventilated wet bulb thermometer functioning as an integrating sensor.

The WBGT index is incorporated into ISO7243, to estimate heat stress on workers. It takes into account whether workers are exposed to heat with solar radiation or without. Equation 8.6 shows the calculation for conditions with and without solar radiation.

**Equation 8.6**

Indoors or outdoor with no heating by sun
WBGT = 0.7 NWB + 0.3 GT

Outdoor exposure to the sun
WBGT = 0.7 NWB + 0.2 GT + 0.1 T

The resultant WBGT values are then compared with permissible heat exposure threshold limit values to take into account metabolic factors via a workload schedule. These are expressed as work–rest regimes over a one-hour period. Therefore, care should be taken in gathering the data to ensure it is the moving average of WBGT over the one-hour period. Table 8.1 shows the recommended maximum WBGT indices or the work–rest regimes.

Area heat stress monitors are on the market to make the task of measuring and calculating WBGT much simpler. Most automatically calculate WBGT for either an indoor or outdoor environment, as well as the individual parameters obtained from the thermometers. Since the WBGT is an index that does not consider the effect of acclimatisation, gender, clothing or age, there have been suggestions that the limit values of WBGT should be adjusted to take account of these factors. For instance, imagine the effect of heat strain when wearing an impermeable chemical suit compared with a singlet and shorts!

The ACGIH has recommended that the threshold limit value of WBGT is modified for acclimatisation, fitness and clothing (see Table 8.2).

### Table 8.1 Recommended work–rest regimes for WBGT (°C)

<table>
<thead>
<tr>
<th>Work–rest regime</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light</td>
</tr>
<tr>
<td>Continuous work</td>
<td>30.0</td>
</tr>
<tr>
<td>75% work/25% rest each hour</td>
<td>30.6</td>
</tr>
<tr>
<td>50% work/50% rest each hour</td>
<td>31.4</td>
</tr>
<tr>
<td>25% work/75% rest each hour</td>
<td>32.2</td>
</tr>
</tbody>
</table>

### Table 8.2 Modified threshold limit values for WBGT

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Threshold limit values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers un-acclimatised or not physically fit</td>
<td>−2.5°C</td>
</tr>
<tr>
<td>Workers wearing cotton overalls</td>
<td>−2°C</td>
</tr>
<tr>
<td>Workers wearing a winter work uniform</td>
<td>−4°C</td>
</tr>
<tr>
<td>Workers wearing a permeable water barrier</td>
<td>−6°C</td>
</tr>
</tbody>
</table>
Example 8.1

A laundry press operator (who operates the press by pushing the heated bench and standing on a foot pedal concurrently) is exposed to the following conditions:

\[ DB = 32°C \]
\[ NWB = 29°C \]
\[ GT = 41°C \]

What is the WBGT and what work–rest regime is suggested?

Answer:

\[
WBGT = 0.7 \times NWB + 0.3 \times GT \\
= 0.7 \times (29) + 0.3 \times (41) \\
= 32.6°C
\]

The recommended work–rest regime would be 25 per cent work and 75 per cent rest each hour. This was determined by assuming a light workload.

Limitations of WBGT

As with all of the environmental heat stress indices, WBGT does not take into account the physical condition of the individual as measured by parameters such as water and electrolyte balance or cardiovascular heat transport capabilities. It also does not provide a good differentiation between humid conditions that prove strenuous or dry environments which do not result in excessive physiological strain. It is recognised that WBGT may have a limited value as a predictor of physiological strain at the higher heat stress levels that may be encountered in industry.

As an evaluation technique, the WBGT method is at best an imprecise indicator of the heat load experienced by a worker. Assumptions must be made regarding the worker’s degree of acclimatisation and physical fitness. The exposure limit must be adjusted for metabolic work rate and clothing. Since work rates and metabolic heat production are estimated, errors can be as high as 30 per cent.

Heat stress index

The heat stress index is based on heat exchange. It considers the ratio of the body’s heat load from metabolism, convection and radiation to the evaporative cooling of the environment. The heat stress index is based on a model of heat exchange which assumes a

<table>
<thead>
<tr>
<th>Heat Stress Index</th>
<th>Effect of eight-hour exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>–20</td>
<td>Mild cold strain</td>
</tr>
<tr>
<td>0</td>
<td>No thermal strain</td>
</tr>
<tr>
<td>10–30</td>
<td>Mild to moderate heat strain. Little effect on physical work, but possible decrement on skilled work.</td>
</tr>
<tr>
<td>40–60</td>
<td>Severe heat strain, involving threat to health unless physically fit. Acclimatisation required.</td>
</tr>
<tr>
<td>70–90</td>
<td>Very severe heat strain. Personnel should be selected by medical examination. Ensure adequate water and salt intake.</td>
</tr>
<tr>
<td>100</td>
<td>Maximum strain tolerated by fit, acclimatised young men</td>
</tr>
<tr>
<td>Over 100</td>
<td>Exposure time limited by rise in deep-body temperature.</td>
</tr>
</tbody>
</table>

Source: Olesen 1985, p. 21
constant skin temperature of 35°C. It can be determined using Equation 8.7.

**Equation 8.7**

\[ 	ext{HSI} = \frac{E_{\text{req}}}{E_{\text{max}}} \times 100 \]

Where:
- \( E_{\text{req}} \) is the metabolic heat production rate less the heat rate loss by radiation and convection (W.m\(^{-2}\))
- \( E_{\text{max}} \) is the maximum evaporative loss rate that can occur (W.m\(^{-2}\))

An upper limit of 390 W.m\(^{-2}\) is assigned to \( E_{\text{max}} \); this corresponds to a sweat rate of 1L.hr\(^{-1}\) for a typical man. An HSI of 100 represents the upper limit of the prescriptive zone. If \( E_{\text{req}} > E_{\text{max}} \) the body cannot maintain equilibrium and its temperature begins to rise. Equation 8.8 illustrates how \( E_{\text{req}} \) is calculated.

**Equation 8.8**

\[ E_{\text{req}} = M - R - C \]

Where:
- \( M \) is the metabolic work rate (W.m\(^{-2}\))
- \( R \) is the radiation heat loss rate (W.m\(^{-2}\))
- \( C \) is the convective heat loss rate (W.m\(^{-2}\))

A number of equations are used to calculate \( E_{\text{max}} \) and \( E_{\text{req}} \). \( E_{\text{req}} \) is the sum of the metabolic work rate, radiation heat loss and convective heat loss. It is important to note that where the radiant temperature is more than 35°C, the radiant temperature will actually appear negative. This means that there is an overall gain of heat to the body. Once the HSI is calculated this is compared with Table 8.3.

**Equation 8.9**

\[ R = 4.4(35 - t_r) \text{ \text{clothed}} \]
\[ R = 7.3(35 - t_r) \text{ \text{unclothed}} \]

Where:
- \( R \) is the radiation heat loss rate (W.m\(^{-2}\))
- \( t_r \) is the radiant temperature (°C)

**Equation 8.10**

\[ C = 4.6v^{0.6}(35 - t_a) \text{ \text{clothed}} \]
\[ C = 7.6v^{0.6}(35 - t_a) \text{ \text{unclothed}} \]

Where:
- \( C \) is the convective heat loss rate (W.m\(^{-2}\))
- \( v \) is the air velocity (m.s\(^{-1}\))
- \( t_a \) is the air temperature (°C)

**Equation 8.11**

\[ E = 7v^{0.6}(56 - p_v) \text{ \text{clothed}} \]
\[ E = 11.7v^{0.6}(56 - p_v) \text{ \text{unclothed}} \]

Where:
- \( E \) is the evaporative heat loss rate (W.m\(^{-2}\))
- \( v \) is the air velocity (m.s\(^{-1}\))
- \( p_v \) is the partial pressure of water vapour (mbar)

If the HSI is more than 100, the exposure duration is limited by an increase in core body temperature. For an HSI more than 100, the allowable exposure time (AET) is determined using Equation 8.12.

**Equation 8.12**

\[ \text{Allowable exposure time} = \frac{2440}{E_{\text{req}} - E_{\text{max}}} \]

The application of the HSI is demonstrated in Example 8.2.
Example 8.2

A foundry worker is exposed to the following conditions:

- \( t_a = 30^\circ C \)
- \( t_{wb} = 20^\circ C \)
- \( t_r = 45^\circ C \)
- \( v = 0.5 \text{ m.s}^{-1} \)
- \( M = 165 \text{ W.m}^{-2} \)

Determine the HSI and interpret the results.

Answer:

\[
C = 4.6 \times 0.6 \times (35 - t_r) \text{ clothed}
\]
\[
= 4.6 \times (0.5)^{0.6} \times (35 - 30)
\]
\[
= 15.17 \text{ W.m}^{-2}
\]

\[
R = 4.4 \times (35 - t_r) \text{ clothed}
\]
\[
= 4.4 \times (35 - 45)
\]
\[
= -44 \text{ W.m}^{-2}
\]

\[
E_{req} = M - R - C
\]
\[
= 165 - (-44) - 15.17
\]
\[
= 194 \text{ W.m}^{-2}
\]

\[
E = 7 \times 0.6 \times (56 - p_a) \text{ clothed}
\]
\[
= 7 \times (0.5)^{0.6} \times (56 - 24)
\]
\[
= 148 \text{ W.m}^{-2}
\]

Interpretation: exposure time is limited by risk in deep body temperature.

\[\text{AET} = \frac{2440}{E_{req} - E_{max}}\]
\[
= \frac{2440}{(194 - 148)}
\]
\[
= 53 \text{ minutes}
\]

**Required sweat rate**

One of the most recently developed heat stress indices is the required sweat rate (ISO7933). This is a comprehensive, yet complex index that considers many factors that can affect the body’s response to heat. Data is required about the dry bulb temperature, wet bulb temperature, humidity, air velocity, globe temperature, thermal insulation property of clothing, metabolic work rate and posture. It predicts the sweat rate, evaporation rate and skin wettedness. If thermal equilibrium is maintained, there should not be a risk of heat stress. If thermal equilibrium is not established, then the amount of time to reach an upper limit of heat storage should be determined.

### CONTROLS FOR HEAT

Minimising exposure to heat is best achieved using an integrated approach based on the hierarchy of control. Where heat is identified as a risk, a policy should be drawn and procedures developed to incorporate issues such as:

- defining the nature and magnitude of hot work and any regulatory requirements for compliance (risk identification)
- methods of evaluating exposure to heat (environmental vs. physiological) (risk evaluation)
- pre-employment medicals and fit-for-work testing
- acclimatisation
- clothing and personal protective equipment
- diet, fluid replacement and hydration
- engineering controls including ventilation and cooling systems
- training for personnel exposed to hot conditions.

**Risk identification**

Identifying heat as a potential problem within a workplace should not be difficult. Chapter 3 outlines methods for hazard identification.

The organisation should also investigate regulatory requirements for heat stress and also thermal comfort. Health-care personnel may also be able to identify cases of heat-related illness. Injury or absenteeism records could be consulted, although often heat is not identified as a contributing factor.
**Risk evaluation**

Some Australian States and Territories have adopted heat stress indices within their legislation for regulating occupational health and safety risks. Others take more of a risk management approach. Depending upon the nature of work, physiological monitoring might be conducted. More commonly, environmental monitoring of the work conditions is performed. These can then be compared with the appropriate benchmarks such as ISO7243, the ACGIH threshold limit values for WBGT, the table of effects for HSI or the allowable time before an excessive increase in body temperature for the required sweat rate.

**Pre-employment medicals and fit-for-work testing**

Medical surveillance involves evaluating an individual’s risk of suffering adverse effects from excessive exposure to heat, treatment of heat-related disorders and review of information from any incidents related to heat. Before workers are placed in a heat-related job, a medical physician should conduct a physical examination (including special attention to the cardiovascular, respiratory and nervous systems, skin, liver, kidney and obesity) and check the medical and work history of the person, with an emphasis on previous problems with heat stress; ascertain any personal habits that might increase the risk of heat intolerance, such as use of prescription and over-the-counter drugs and alcohol, and access the person’s ability to wear and use personal protective equipment to minimise exposure to heat.

A good level of general aerobic fitness, reduction of body fat levels, adequate hydration and reduction in alcohol consumption can all assist in minimising heat-related illness. Smoking also should be avoided for both health and fitness reasons. Alcohol tends to cause dehydraition and, as such, can further exacerbate the effects of hot conditions, leading to heat-related injury.

Fitter individuals display an earlier onset of sweating, an increased production of sweat, a lower percentage use of their maximum aerobic fitness (VO2 max) and a maximum heart rate at any given workload. High levels of body fat result in a greater production and storage of heat. Individuals with high body fat levels place a greater strain on the cardiovascular system, thereby taxing a greater percentage of the maximum aerobic fitness. This leads to an increased production of heat, further adding to the risk of sustaining a heat-related injury.

**Acclimatisation**

Acclimatisation is a process that allows workers to become used to heat. Where workers are away from hot conditions for more than several days, a re-acclimatisation schedule should be adopted.

**Clothing and personal protective equipment**

Clothing can contribute to the overall heat storage of the body if it has a high insulation factor (Iclo). A minimum of clothing should be worn to work safely where the air temperature is less than 35°C. It is preferential to wear lightweight cotton clothing with a light colour if outdoors.

Work such as firefighting or emergency response personnel require the wearing of impervious clothing that may restrict evaporation of sweat. While this clothing is required for occupational health and safety reasons, the time within the clothing should be limited. Ice-cooled vests or icepacks can be worn around the neck to assist cooling of the body.
Diet, fluid replacement and hydration

Workers should ensure their diet is nutritionally sound, with adequate electrolytes. It is better to take more frequent and smaller meal breaks rather than one long break with one large meal since this can cause lethargy and tiredness as blood is shunted to the stomach. The following recommendations are provided to maintain hydration:

- consume at least 250 mL of water or a non-carbonated beverage prior to each shift; avoid coffee or tea as these products contain caffeine, which promotes dehydration
- consume approximately 200–250 mL of water or a non-carbonated beverage every 15–20 minutes during shifts; again, avoid the use of coffee, tea or soft drinks
- cool fluids should be ingested rather than cold, as cold fluids may cause vasoconstriction, thereby reducing blood flow to the skin.

Engineering controls

The suitability of engineering controls to minimise exposure to heat will depend upon the nature of the workplace. For instance, installing air-cooling systems within deep mines is expensive and time-consuming. The types of engineering controls that are available include:

- insulation of ceilings to minimise solar heat transfer
- reflective blinds within offices or factories to alter the path of transmission of heat
- glass or tinted windows
- exhaust ventilation such as part enclosures or local hoods above heat-generating processes
- forced air ventilation to increase airflow (where air temperature is less than 35°C; above 35°C, an increase in airflow will actually add to the heat load of the worker)
- cooled air from an HVAC system or using refrigerated air.

Training

Workers and supervisors should be trained to recognise heat stress symptoms and control the risk associated with it. Before working in hot conditions for the first time, pre-placement training should be offered. The training should include:

- an outline of thermoregulation, symptoms of heat illness, acclimatisation, work demands and clothing
- a description of first-aid measures for each heat-related disorder
- emphasis on the hygiene practices that are recommended such as adequate hydration, individual responsibility and self-pacing of work.

EXPOSURE TO COLD AND MODERATELY COLD ENVIRONMENTS

For workers in the northern states of Australia, exposure to cold and moderately cold environments is barely considered to be an occupational hygiene issue! However, for those working outdoors during the winter months in southern states or inside workplaces such as coldrooms, cold stress can be a real problem. Just as excessive exposure to heat can place the body at risk, significant cooling of the body from its optimum core temperature can also be hazardous. Clinically, a state of hypothermia can be said to exist when the body’s core temperature falls to about 35°C. Below this
temperature the risk of fatality increases, until
at temperatures below 30°C the imminent
death of an individual is likely due to cardiac
arrest.

**The effects of exposure to cold**

The first sign of the risk associated with
exposure to cold conditions is pain, then
numbness of the extremities (especially the
fingers and toes). This is due to the body
shunting warm blood to the core of the body,
away from the non-vital areas such as the
hands, feet, nose, cheeks and ears. This can
lead to frostbite. ‘Trenchfoot’ or immersion
foot can also occur. As the cardiovascular
system attempts to compensate for the heat
loss from the body, the metabolic rate rises.
Maximum shivering occurs when the core body
temperature is 35°C. This is known as
hypothermia. As the body’s temperature
decreases, cognitive reaction times slow, the
metabolic rate increases in an attempt to
compensate for heat loss and the body shivers.

**Cold stress indices**

Compared to heat stress, the number of
indices available to predict outcomes and
control exposure for cold exposure is
extremely limited. The two main techniques
are the still shade temperature and ACGIH TLV
for cold stress.

**Still shade temperature**

This index considers the outdoor environ-
mental conditions, assuming that there is no
solar load and no heat effect. Alterations are
made if solar heat is absorbed by the body or
if wind speed increases. An increase in wind
speed will affect the windchill factor.

**ACGIH TLV for cold stress**

The ACGIH provides a method for assessing
exposure to cold. These are expressed as the
equivalent chill temperature (ECT). For
exposed skin, the ACGIH recommends that
workers should not be continuously exposed
to an ECT of less than –32°C. The ECT
considers the estimated wind speed and actual
temperature. It is available in the ACGIH’s TLV
and BEI document.

The ACGIH also suggests that superficial
freezing will occur at temperatures below –1°C,
regardless of wind speed. To minimise expos-
ure time, work-warming regimes can be used in
a similar method to the work–rest regimes
from the WBGT index for heat exposure.

**Controls for cold**

Exposure to extremely cold environments may
lead to hypothermia, where the body’s core
body temperature falls to below about 35°C.
However, it is not only the air temperature
which impacts on the risk to cold stress. Low
air temperatures aggravated by the wind,
immersion in water and working in wet
clothing all increase the risk. Depending upon
the exposure situation, a combination of
administrative controls and personal pro-
tective equipment may be the best option to
minimise risk of cold-induced illness. Some
examples of controls include:

- **warm air jets, hot plates or radiant
  heaters**
- **insulating handles of tools with
  thermal insulating materials**
- **anti-contact gloves with padding and
  insulation characteristics**
- **shielding the work area from the
  wind by enclosures (e.g.
  telecommunications workers repairing
  joining lines while huddled under
  tents)**
Exposure to heat typically results in the body compensating for any temperature gains to maintain homeostasis. However, where this is not possible, a resulting heat strain may occur. Managing risks associated with exposure to heat or cold can be conducted through either physiological or environmental monitoring.

Environmental indices such as WBGT, ET, P4SR, HSI and required sweat rate can be used for exposure to heat. The still shade temperature index and ACGIH TLV can be used for evaluating and controlling exposure to cold stress.

**SUMMARY**

- wearing water-impermeable or water-repellent clothing and changing outer clothing when it becomes wet
- wearing vapour barrier boots or changing socks frequently
- heated warming shelters for warming periods
- maintenance of hydration levels with warm soups and drinks.

**BIBLIOGRAPHY AND FURTHER READING**

American Conference of Governmental Industrial Hygienists 2003, *TLVs and BEIs*, ACGIH, Cincinnati, Ohio


Hanson, M.A. and Graveling, R.A. 1997, *Development of a Code of Practice for Work in Hot and Humid Conditions in Coal Mines*, Institute of Occupational Medicine, Edinburgh


Physical occupational hygiene hazards such as radiation and pressure are often overlooked, since they cannot be sensed through sight, smell, hearing, taste or touch. However, while we may not easily perceive the actual hazard, the consequences of exposure can be devastating.

Arguably the world’s worst industrial incident involving radiation occurred on 26 April 1986 at the Chernobyl Power Plant in the Ukraine (former Soviet Union). An overheated reactor caused a meltdown of the core, resulting in two explosions that blew the top off the reactor building, releasing clouds of deadly radioactive material into the atmosphere for more than ten days. The people of Chernobyl were exposed to radioactivity 100 times greater than the Hiroshima bomb of 6 August 1945. After more than a decade, babies are still being born with no arms, no eyes or only stumps for limbs.

Radiation is a source of energy that is made up of waves with different frequency and wavelength characteristics, and alpha and beta particles. Radiation can be categorised into two groups: non-ionising and ionising. The Chernobyl and Hiroshima incidents are examples of exposure to ionising radiation.

In this chapter we take a brief look at the physics of radiation, radioactivity and radioactive decay. The health effects from ionising and non-ionising radiation will be discussed, together with an outline of how to monitor for radiation. A small section of the chapter will be apportioned to pressure, its effects and sources.

IONISING RADIATION

Believe it or not, we are all exposed to natural ionising radiation. Some of it originates from radioactive materials in rocks and soil. Others are produced by cosmic rays that continually bombard us from beyond earth. In the workplace, workers may be exposed to ionising radiation in hospitals, dental clinics, materials testing laboratories and uranium mining. By definition, ionising radiation refers to any material that can ionise the atoms or molecules of the material it passes through. This can cause significant damage to biological tissue. The kinds of radiation of major concern are $\alpha$, $\beta$, $\gamma$ and X rays, as well as protons, neutrons and other particles such as pions.

But what makes a substance radioactive? To explain this, the structure and properties of a nucleus need to be understood.

Nuclear physics

As you would be aware, the building blocks of life are atoms. Atoms combine to form molecules, and so the structural complexity increases. Atoms all have common components: a nucleus and electrons. Electrons are
negatively charged particles that orbit around the nucleus. The nucleus is considered as an aggregate of two types of particles (nuclides): protons and neutrons. A proton has a positive charge and mass. It is generally accepted that the mass of a proton is $1.6726 \times 10^{-27}$ kg.

The neutron has no charge but its mass is virtually identical to that of a proton ($1.6749 \times 10^{-27}$ kg). The number of protons in an atom is called the atomic number (Z). Its atomic mass number (A) is the sum of neutrons and protons. Therefore, the number of neutrons is the difference between A and Z. This is shown in Equation 9.1.

**Equation 9.1**

$$A = Z + X$$

Where:
- A is the atomic mass number
- Z is the atomic number
- X is the chemical symbol for the element.

Most chemistry texts represent elements as X. For instance, $^{14}$N represents a nitrogen atom that has 7 protons and 7 neutrons. Many atoms do not have an equal number of neutrons and protons. If the nucleus of an atom contains unequal numbers of neutrons and protons, the element is known as an isotope. The most common example of this is carbon, which has the isotopes $^{12}$C, $^{13}$C, $^{14}$C, $^{15}$N and $^{16}$O. If isotopes do not occur naturally, they can be produced in the laboratory through nuclear reaction. In fact, all elements on the periodic table beyond uranium (Z > 92) do not occur naturally and can only be produced artificially.

### Radioactivity

Once we understand that atoms consist of protons, neutrons and electrons, we can expand this to describe radioactivity. Within a stable nucleus, protons must exist harmoniously without repulsion. But how does this occur? With large numbers of protons (that are positively charged) it would be expected that these would be electrically repulsed from each other, remembering that like-charges repel. However, another force known as strong nuclear force holds the protons together.

Radioactivity is the term given to the radiation energy that is emitted from a substance without any external stimulus. This occurs from disintegration or decay of an unstable nucleus. Certain isotopes are not stable under the action of strong nuclear forces, causing them to emit radiation. But this emitted radiation is not the same for all elements. The three main types of radiation are:

- **α rays that are positively charged particles and are simply the nuclei of helium atoms ($^4$He)**
- **β rays that are negatively charged (electrons)**
- **γ rays that are high-energy photons (a photon is a tiny particle containing energy).**

**Alpha decay**

Alpha (α) decay occurs where an element loses two protons and two neutrons, that is a helium atom ($^4$He). This usually occurs when an unstable atom’s nucleus decays to produce an

$$^{226}_{88}\text{Ra} \rightarrow ^{222}_{86}\text{Rn} + ^4\text{He}$$

**Figure 9.1 Decay of radium**
element with a lower atomic mass and number. The resultant element is known as the daughter. Therefore, with α decay an entirely different element is formed. An example of this is the decay of radium-226 to radon-222 (Figure 9.1).

Radon is used in hospitals for certain therapies, although the main hazard is from inhaling dust in the air. Radon build-up is a health consideration in uranium mines. Recently, however, radon build-up in homes has become a concern, especially in North America. Many deaths from lung cancer can be attributed to radon exposure and Western Australia also has significant levels of radon in the soil. Radon gas from the soil can enter a home or building through dirt floors, hollow-block walls, cracks in the foundation floor and walls, and openings around floor drains, pipes and sump pumps.

Beta decay

Beta (β) decay occurs when a nucleus decays with the emission of an electron or β particle. Beta decay does not cause a change in the number of protons or neutrons in a nucleus. Therefore, the parent and daughter elements have the same atomic mass number. For each decay, the parent nucleus loses a charge of −1 (electrons are negatively charged); therefore, the daughter nucleus has an extra positive charge (Figure 9.2). A neutrino is also emitted. This particle has no charge and is believed to have no mass.

It is important to realise that the electrons that are lost in this process are not those from the orbit of the nucleus. Instead, an electron is created within the nucleus itself. This is one reason that electrons emitted through beta decay are known as β particles. Having said that β particles are negatively charged, we will now introduce the principle of positron (β⁺) decay. Some isotopes have a much greater number of protons than neutrons. With these elements, radioactive decay will result in the emission of a positron (sometimes called e⁺ or β⁺) instead of an electron. A positron has a positive charge of +1. Since it is like an electron, except for its opposite charge, the positron is called the antiparticle.

Gamma decay

Gamma (γ) decay occurs where a nucleus is in an excited state and it moves into a lower energy state, emitting energy or a photon. Gamma rays are photons with very high energy. They do not carry any charge; therefore, there is no change in the element as a result of γ decay.

Usually, atoms get into this ‘excited state’ following previous radioactive decay like β decay. It follows, then, that γ radiation often accompanies or follows β decay.

Finally, while both γ and X rays are photons, γ radiation is produced by a nuclear process. X rays are created by an electron–atom interaction.

Half-life and rate of decay

Radioactive decay is a random process. Nuclei will not all decay at the same time, but over a period of time. The number of decays (ΔN) that occur over a time period (Δt) will be determined from the total number (N) of radioactive nuclei present. We also must consider the decay constant (λ), which differs for individual isotopes. This is illustrated in
Equation 9.2. Note that the number of decays is negative, indicating a loss.

**Equation 9.2**

\[ \Delta N = -\lambda N \Delta t \]

Where:

- \( \Delta N \) is the number of decays
- \( \lambda \) is the decay constant
- \( N \) is the total number of radioactive nuclei
- \( \Delta t \) is the time period

With some arithmetic manipulation, Equation 9.2 can be extrapolated to express the total number of radioactive nuclei (N). This is known as the radioactive decay law and is shown as Equation 9.3.

**Equation 9.3**

\[ N = N_0 e^{-\lambda t} \]

Where:

- \( N \) is the total number of radioactive nuclei
- \( N_0 \) is the number of nuclei present at \( t = 0 \)
- \( \lambda \) is the decay constant
- \( t \) is time (sec)

The rate of decay each second (\( \Delta N/\Delta t \)) is called the activity of the element. Activity (A) is the number of decays per second from a sample. The SI unit is the bequerel (Bq) or one disintegration per second. Previously, the curie (Ci) was used, although this is a very large unit. One curie is about \( 3.7 \times 10^{10} \) Bq. Equation 9.4 shows how to calculate activity from initial activity.

**Equation 9.4**

\[ A = A_0 e^{-\lambda t} \]

Where:

- \( A \) is the activity
- \( A_0 \) is the initial activity (Bq)
- \( \lambda \) is the decay constant
- \( t \) is time (sec)

Rather than expressing the decay constant, the rate of decay is often specified as its half-life (T\(_{1/2}\)). This refers to the time it takes for half the original amount of isotope to decay. Half-lives vary between percentages of seconds to millions of years. Half-life can also be simply expressed as \( 0.693/\lambda \). The longer the half-life, the more slowly it decays. Example 9.1 provides an example involving the calculation of half-life as related to activity.

**Example 9.1**

Radon-222 from radium has a half-life of 3.823 days. What is the activity of a sample of \(^{222}\)Rn after 3 days, if the initial activity is 5 Bq?

Answer:

\[
\lambda = \frac{0.693}{(3.823 \times 24 \times 60 \times 60 \text{ (s)})} = 2.1 \times 10^{-6} \text{ s}^{-1}
\]

\[
A = A_0 e^{-\lambda t} = 5000 e^{-0.0000021 \times [3 \times 24 \times 60 \times 60]} = 2.9 \text{ kBq}
\]

**Sources of ionising radiation**

In the broad picture of industry as a whole, ionising radiation is found in only a small proportion of workplaces. Some examples of sources include:

- **gauges for measuring thickness, density, moisture and levels**
- **checking welding defects in metals-manufacturing workplaces** (non-destructive investigation)
- **smoke detectors**
Health effects of exposure to ionising radiation

Biological damage to the body is dependent on the type of radiation and organ that is exposed. Charged particles such as α and β rays and protons cause ionisation of tissues due to their electrical force. Neutral particles such as X rays and γ ray photons can also ionise atoms in the body.

High doses of ionising radiation destroy body tissues with death occurring immediately or soon after exposure. The symptoms of radiation sickness include a reddening of the skin, a drop in white blood cell count, nausea, fatigue and loss of body hair. The effects of lower doses, however, may not show for years after the exposure and are due to various changes in DNA molecules and chromosomes. There are at least four ways in which low doses of ionising radiation can affect cells:

- **Low doses of ionising radiation can bring about delays in the process of cell division.**
- **Radiation-induced mutations seem to be brought about by the deletion of small pieces of chromosomes during the process of chromosome breakage and repair,** and if such changes occur in egg-producing or sperm-producing cells (somatic cells) they may be inherited by the offspring.
- **Ionising radiation can induce the abnormal growth of cells.** Advanced cancer cells usually have an abnormal complement of chromosomes but other smaller genetic changes may also play a part in carcinogenesis. Since chromosome damage is most likely to happen in dividing cells, ionising radiation is most likely to cause cancer in those parts of the body where cells are actively dividing.
- **Ionising radiation kills rapidly dividing cells.** This specific effect of ionising radiation can, however, be put to good use. Cancer cells produced by human genetic defects or other causes divide rapidly, which is why they are dangerous. Careful application of radiation therapy can therefore be used to kill the cancer cells while leaving normal cells relatively undamaged.

Measuring ionising radiation

As we have already discussed in Chapter 1, all substances are poisons. However, the dose distinguishes between the agent having a therapeutic or hazardous effect. The measurement of ionising radiation is known as dosimetry. This involves measuring the magnitude or strength of the radiation (its activity) and considering the area of the body which is affected.

The activity can be expressed as the curie or bequerel. A useful conversion is that one curie equals $3.7 \times 10^{10}$ disintegration per second and a bequerel is one disintegration per second.

However, while the activity relates to the decay or disintegration of the source, it does not consider the exposure or absorbed dose. Exposure was previously measured by the roentgen (R). One roentgen was defined as the amount of X or γ radiation that deposits 0.878 $x 10^{-2}$ Joules of energy per kilogram of air.
The SI unit for exposure is now coulombs per kilogram (C.kg\(^{-1}\)). There are about 3881 roentgens per C.kg\(^{-1}\).

Absorbed dose is the amount of energy per mass. The SI unit for absorbed dose is the gray (Gy). Previously, it was the rad. One rad is the amount of radiation that deposits energy at a rate of 1.00 \times 10^{-2} \text{ J.kg}^{-1} in any absorbing material. Since the absorbed dose is still a physical unit of dose representing the amount of energy deposited per mass of material, we need to consider the effects of ionising radiation depending on the target organ or site.

The equivalent dose is used in this case. It is the product of the absorbed dose and weighting of the type of radiation. It is measured in sieverts (Sv). For instance, \(\alpha\) rays have a greater mass than \(\beta\) or \(\gamma\) radiation and ionise cells that are closer together. This results in damage ten to twenty times greater than \(\beta\) or \(\gamma\) radiation. Finally, the effective dose provides an indication of the biological effect by considering the tissue that is affected. Table 9.1 shows the weighting factor for several types of radiation.

<table>
<thead>
<tr>
<th>Tissue or organ</th>
<th>Weighting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>bladder</td>
<td>0.05</td>
</tr>
<tr>
<td>bone marrow (red)</td>
<td>0.12</td>
</tr>
<tr>
<td>bone surface</td>
<td>0.01</td>
</tr>
<tr>
<td>breast</td>
<td>0.05</td>
</tr>
<tr>
<td>colon</td>
<td>0.12</td>
</tr>
<tr>
<td>gonads</td>
<td>0.20</td>
</tr>
<tr>
<td>liver</td>
<td>0.05</td>
</tr>
<tr>
<td>lung</td>
<td>0.12</td>
</tr>
<tr>
<td>oesophagus</td>
<td>0.05</td>
</tr>
<tr>
<td>skin</td>
<td>0.01</td>
</tr>
<tr>
<td>stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>thyroid</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 9.2 shows the tissue weighting factors.

### INSTRUMENTATION

Individual particles such as electrons, protons, \(\alpha\) particles, neutrons and \(\gamma\) rays cannot be detected by the senses of the body. A number of detectors have been developed over time to measure ionising radiation. They can be categorised into the following groups:

- **simple detectors** — for radiation detection and contamination monitoring
- **dosimeters** — for monitoring absorbed dose.

#### Simple detectors

One of the most common simple detectors is the Geiger counter. The Geiger counter consists of a cylindrical tube that is filled with gas. The tube acts as a cathode with a wire electrode inside as the anode. The voltage inside the tube is slightly less than that required to ionise the gas atoms.

Therefore, if a charged particle enters the tube, it ionises a few atoms of the gas. This in turn causes a multitude of gas atoms to ionise in a cascade. When they reach the wire anode,
a voltage pulse is sent to a detector and counter. Most Geiger counters are connected to an audible output so a ticking sound is heard. As the frequency of ticks or clicks increases, this reflects the amount of radiation. It is best for the detection of β radiation.

A scintillation counter uses a media such as gas, liquid or solid. This media is called the scintillator. As the radiation particles strike the scintillator, it becomes excited and emits visible light. This light energy is converted into an electrical signal by a photomultiplier tube. As a general rule, this type of meter is best for detecting γ radiation. A typical scintillator is a crystal of sodium iodide (NaI).

**Dosimeters**

Dosimeters are able to provide an accurate measure of absorbed dose. Most are small and can be worn on the worker. Hence they are particularly useful where workers move around and can be exposed to various sources of radiation. The simplest type is the quartz fibre electroscope. In this dosimeter, electrostatically charged quartz fibres are discharged when they are ionised by the radiation source. They are generally used for X and γ rays. The other type is the thermoluminescent dosimeter (TLD). They are usually available in a number of energy ranges and respond to γ, β and X emissions.

As the radiation interacts with the sensitive crystals, light is stored. The total light is proportional to the amount of radiation energy absorbed. TLDs are handy in that they can be reused once the crystals have been annealed. The light energy is released when the crystals are heated at the assessment laboratory.

TLDs have largely replaced the film badge dosimeter. The film badge dosimeter is a piece of film wrapped in a light-tight material. As ionising radiation passes through the film, it changes so that when the film is developed it has darkened.

After film badges or TLDs have been worn for a time, they are returned to an accredited laboratory or provider to determine the dose of radiation. The following principles should be adopted when wearing these badges:

- **Wear the badge at all times when there is a potential for occupational exposure to ionising radiation.**
- **Do not wear the badges if receiving diagnostic or therapeutic medical treatment.**
- **If badges are not being used, they should be stored in an area without radiation from activities (background exposure only) to prevent non-work related exposure.** Refrigeration is advisable where high temperature or humidity are encountered.
- **Film badges must not be kept in vehicles or where elevated temperatures may cause damage (darkening) to the film.** This damage may be indistinguishable from darkening due to radiation exposure.
- **A control badge should be kept with other badges not in use.** It should also be returned with the rest of the badges for the same wear period. The control is used to determine background radiation at a location and any dose received by the badges in transit. Any recorded dose is subtracted from the other badges, so it should not be used for any other purpose.
- **The badge should be clipped on the collar of a shirt or dress, the front portion of the torso or at the waist.** It is advisable to continue using the chosen position for a full wear period.
- **If the hands are likely to be subjected to more radiation exposure than other parts of the body, rings or wrist badges should also be worn.**
Standards for ionising radiation

In Australia, each State and Territory has responsibility for controlling exposure to radiation (Table 9.3). These regulations are based on the NH&MRC’s recommended radiation protection standards for individuals exposed to ionising radiation. To control random effects, the effective dose limit is suggested as 20 mSv per year for uniform irradiation of the whole body. For the general public, the level is 1 mSv each year. For localised exposure to the hands, feet and skin, a limit of 500 mSv per year has been set for radiation workers, to avoid acute effects from exposure. For other tissues, lower limits have been set (e.g. 150 mSv for the lens of the eye).

If radiation is not uniform across the body, then the appropriate tissue weighting factors (Table 9.2) should be used. Pregnant workers should not be exposed to more than 2 mSv to the abdomen for the remainder of the pregnancy (measured as an equivalent dose).

The ACGIH suggests an effective dose of 50 mSv in any single year (expressed as the TLV). Otherwise its recommendations for exposure are identical to that of Australia. Another useful reference is AS2243.4 (Int). This provides safety requirements for laboratories and precautions needed to prevent the exposure of workers and members of the public to excessive levels of radiation where sources of ionising radiation are used. The recommended annual effective dose limit for members of the public is 1 mSv per year, averaged over the person’s lifetime.

NON-IONISING RADIATION

Non-ionising or electromagnetic radiation is essentially energy waves that are composed of electric (E field) and magnetic field (H field) components. This energy is insufficient to eject electrons from atoms, thus it is not able to ionise other matter. The electric and magnetic fields are orthogonal to each other and orthogonal to the direction of propagation of the wave. These two fields have the same frequency and wavelength (thus the same speed) but travel in mutually perpendicular planes.

The electric field strength (E) is defined as the force experienced by a positive charge placed in an electric field and is measured as newton per coulomb (N.C⁻¹).

### Table 9.3 Contact details for Australian government authorities responsible for radiation

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Responsible body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Capital Territory</td>
<td>Radiation Safety Section, ACT Department of Health and Community Care</td>
</tr>
<tr>
<td>New South Wales</td>
<td>Radiation Control Section, Environment Protection Authority</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>Radiation Health Branch, NT Department of Health &amp; Community Services</td>
</tr>
<tr>
<td>Queensland</td>
<td>Radiation Health, Department of Health</td>
</tr>
<tr>
<td>South Australia</td>
<td>Radiation Protection Branch, South Australian Health Commission</td>
</tr>
<tr>
<td>Tasmania</td>
<td>Department of Community and Health Services</td>
</tr>
<tr>
<td>Victoria</td>
<td>Radiation Safety Section, Department of Human Services</td>
</tr>
<tr>
<td>Western Australia</td>
<td>Radiation Health Section, Health Department of WA</td>
</tr>
</tbody>
</table>
The magnetic field occurs when the charges are moving and can be measured either as the magnetic field strength (H) or magnetic flux density (B). The magnetic field strength has units of ampere per metre (A.m\(^{-1}\)). Radio frequency (RF) radiation is usually expressed in terms of H, with the exposure standards for magnetic fields of radio waves and microwaves given in units of H\(^2\). The magnetic flux density has the unit tesla (T), previously gauss (G).

There are 10,000 gauss in a tesla. Magnetic fields from powerlines, electric motors, monitors and other low-frequency equipment is usually monitored this way.

Both the NH&MRC and ACGIH recommend occupational exposure standards to static magnetic flux density. For instance, the ACGIH suggests occupational exposure should not exceed 60 mT (600 G) for the whole body or 600 mT for the extremities. A ceiling value of 2 T and 5 T has also been suggested for the whole body and the extremities, respectively. For people wearing cardiac pacemakers and similar medical electronic devices, the ceiling is 0.5 mT (5 G).

Electromagnetic waves travel through a vacuum at around 3 \(\times\) 10\(^8\) m.s\(^{-1}\) (the speed of light in a vacuum). They are usually expressed as the electromagnetic spectrum and have a broader range of frequencies (see Table 9.4). In order of increasing frequency, these are:

- **radio frequency**
- **infrared (meaning ‘below red’)** — the eyes cannot detect this IR radiation but our skin feels it as heat
- **visible light** — with wavelengths from about 400 nm for violet light through to about 700 nm for red light; our eyes are most sensitive to light in the middle of this range, such as yellow light with a wavelength of about 550 nanometres (nm) (1 nm = 10\(^{-9}\) m)
- **ultraviolet (meaning ‘above violet’)** — causes sunburn and changes in skin pigmentation; UV radiation can also cause skin cancer and eye damage
- **X rays**
- **gamma rays** — these can be classed as either ionising or non-ionising radiation.

### Ultraviolet radiation

Ultraviolet radiation is divided into three types — A, B and C. Each is characterised by a different wavelength.

- **UV-A ranges from 315–400 nm**
- **UV-B ranges from 280–315 nm**
- **UV-C ranges from 100–280 nm.**

The wavelengths with the highest risk to people range from 180 to 400 nm, with wavelengths around 270 nm being the most damaging. The main organs affected from exposure to UV radiation are the skin, eyes and possibly the immune system. Reddening or burning
(erythema) of the skin and skin cancer may result from excessive skin exposure. Some photosensitising chemicals such as creosote, coal tar pitch (from bitumen) and photograph-developing chemicals can cause the skin to be more susceptible to UV-B. Cataracts, conjunctivitis and keratosis may affect the eye. The parts of the eye that may be damaged from exposure to UV radiation are the conjunctiva, cornea, lens and retina. Short wavelength UV radiation principally absorbs at the cornea, while long wavelength UV radiation is transmitted through the eye and focuses on the retina.

**Exposure standards**

UV radiation can be measured using a photoelectric sensor, although from an occupational hygiene perspective it is important that we consider the effects of each type of UV radiation individually.

The exposure standards promulgated by the NH&MRC in Australia consider the type of UV radiation and the organ affected. The ACGIH also has threshold limit values set for exposure to non-ionising radiation.

**UV-A (skin) and UV-B/C (skin or eyes)**

For unprotected skin or eyes, exposure is calculated as the effective irradiance, relative to a monochromatic source of UV radiation at 270 nm. Individual irradiances are considered, together with the relative spectral effectiveness of the source. Equation 9.5 illustrates how to calculate the effective irradiance (E_{eff}).

**Equation 9.5**

\[ E_{eff} = \sum E \lambda S \lambda . \Delta \lambda \]

Where:

- \( E_{eff} \) is the effective irradiance relative to a monochromatic source at 270 nm (W.cm\(^{-2}\))
- \( E_\lambda \) is spectral irradiance (W.cm\(^{-2}\).nm\(^{-1}\))
- \( S_\lambda \) is relative spectral effectiveness
- \( \Delta \lambda \) is bandwidth (nm)

For a single wavelength, the effective irradiance is simply the product of spectral irradiance and relative spectral effectiveness. This is expressed over an eight-hour period. However, where more than one wavelength is involved (this is known as broadband radiation), the effective irradiance of the source is calculated by weighting individual spectral irradiances against the peak of the spectral effectiveness curve (270 nm).

To make the effective irradiance into a useable value, the permitted exposure time is determined by dividing 0.003 J.cm\(^{-2}\) by \( E_{eff} \) (W.cm\(^{-2}\)). This is shown as Equation 9.6, and Example 9.2 explains this concept.

**Example 9.2**

A UV radiation source had a spectral irradiance (E\(_\lambda\)) as follows.

<table>
<thead>
<tr>
<th>( \lambda )</th>
<th>( E_\lambda ) (µW.cm(^{-2}).nm(^{-1}))</th>
<th>( S_\lambda )</th>
<th>( E_{eff} ) (µW.cm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>280</td>
<td>1.8</td>
<td>0.88</td>
<td>1.8 \times 0.88 \times 10 = 15.8</td>
</tr>
<tr>
<td>290</td>
<td>2.9</td>
<td>0.64</td>
<td>2.9 \times 0.64 \times 10 = 18.6</td>
</tr>
<tr>
<td>300</td>
<td>3.5</td>
<td>0.30</td>
<td>3.5 \times 0.30 \times 10 = 10.5</td>
</tr>
</tbody>
</table>

What is the permitted exposure time?

Answer:

\[
E_{eff} = \sum E_\lambda S_\lambda \Delta \lambda
\]

\[= 45 \text{ µW.cm}^{-2}\]

Permitted exposure time = \( \frac{0.003}{E_{eff}} \)

\[= 0.003 \text{ J.cm}^{-2}/45 \times 10^{-6} \text{ W.cm}^{-2} \]

\[= 67 \text{ seconds} \]
Equation 9.6
Permitted exposure time = 0.003/E_{eff}
Where:
- Permitted exposure time (sec)
- $E_{eff}$ is effective irradiance (W.cm$^{-2}$)

**UV-A (eyes)**

When assessing the effects of exposure of UV-A radiation to the eyes, a single limit is used. The general recommendations are that radiant exposure to UV-A of the eyes should not exceed 1.0 J.cm$^{-2}$ for exposure periods of less than $10^3$ seconds. For periods of more than $10^3$ seconds, the total irradiance should not exceed 100 mW.cm$^{-2}$. The permitted exposure time can then be calculated using Equation 9.7.

Equation 9.7
Permitted exposure time = 1.0/Irradiance
Where:
- Permitted exposure time (sec)
- Irradiance is W.cm$^{-2}$

**Visible and near infrared radiation**

As with the other components of the electromagnetic spectrum, visible light is emitted when a material is energised. This causes electrons to drop from a higher-energy orbital to a lower one and give up a quantum of energy (photon) in the form of light.

Visible light consists of a number of spectra, ranging between around 400 nm (violet light) to 500 nm (green light), and 700 nm (red light). The spectra can be seen when light is separated into various components, such as by shining light through a prism or as a rainbow. In a rainbow, the longer wavelength spectra (red) lie on the longer arc of the rainbow, while violet is seen toward the base of the rainbow.

The most common sources of visible and near infrared radiation are found in high-energy applications such as furnaces, molten metal and welding.

Similar to exposure to UV radiation, the main health effects of exposure to this type of radiation occur with the eyes. Visible light and near IR radiation (400 – 1400 nm) pass through the cornea and are focused on the retina.

**Exposure standards**

Visible lighting levels are assessed against the AS1680 series for illumination. Chapter 11 describes how to monitor for light and compare with the appropriate standard. For infrared radiation, the ACGIH TLV provide recommendations that limit exposure to visible and near IR radiation. The ACGIH TLV for occupational exposure to broadband light and near IR radiation for the eye require knowledge of the spectral irradiance ($L_\lambda$) and total irradiance ($E$) of the source. This is only required where the luminance of the source is more than 1 cd.cm$^{-2}$. If the source were less than this amount, the TLV would not be exceeded. The ACGIH TLV aim to protect against retinal thermal injury from a visible light source. Therefore, if the source has a luminance of more than 1 cd.cm$^{-2}$, Equation 9.8 is used.

Equation 9.8
\[
\sum L_\lambda \cdot R_\lambda \cdot \Delta \lambda \leq 5/\alpha \cdot t^{0.25}
\]
Where:
- $L_\lambda$ is spectral radiance (W.cm$^{-2}$sr.nm)
- $R_\lambda$ is retinal thermal hazard function
- $\alpha$ is viewing angle (rad)

To protect against retinal photochemical injury from chronic blue light exposure, the blue light hazard function ($B_\lambda$) replaces the retinal
thermal hazard function used in Equation 9.8. The maximum time of exposure can be determined using Equation 9.9, where \( L_{\text{blue}} \) is the product of \( L_\lambda \) and \( B_\lambda \). The values of \( L_\lambda \) and \( B_\lambda \) are available in the ACGIH TLV booklet.

**Equation 9.9**

\[
\frac{t_{\text{max}}}{L_{\text{blue}}} = \frac{100 \text{ J} / (\text{cm}^2 \cdot \text{sr})}{(\text{for } t \leq 10^4 \text{ s})}
\]

Where:

- \( t_{\text{max}} \) is permissible exposure duration (s)
- \( L_{\text{blue}} = L_\lambda \times B_\lambda \)

**Lasers**

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Due to their high intensity and monochromatic characteristics, lasers present a hazard even over long distances. The principle of operation lies in the excitation of atoms to a higher energy level. The excited atoms are unstable and emit a photon once returning to ground state.

This emitted light can have wavelengths ranging from infrared to visible, UV and X-ray radiation. Once the photon is emitted it bounces between several mirrors, causing the photon to stimulate the emission of photons with exactly the same wavelength. This cascading effect continues, with more and more photons emitting radiation. All of these light waves are in phase. This means that as they pass between the mirrors, their power intensifies with the emergent light being the laser beam.

Lasers are used in the construction industry for surveying and drilling holes in metals, welding, telecommunications, dentistry, entertainment (lighting, holography, compact discs), printing, for reading universal product codes (bar codes) in supermarkets or stores and in the military for target designation. But does this mean that all lasers are harmful? The answer will depend upon the classification of the laser that is based on its emission limits. The main classes of laser products, from least to most hazardous, are Class 1, 2, 3A, 3B and 4.

AS/NZS2211.1 specifies requirements and procedures designed to protect people from laser radiation. It specifies safe working levels of optical radiation, classifies lasers according to their degree of hazard and sets out detailed protective and control measures appropriate to each class. A statement on the effect of laser radiation on biological tissues is given in addition to the maximum permissible exposures, calculations, a medical surveillance chart and the design of warning labels and signs. Figure 9.3 illustrates an example of a warning sign for laser radiation. Some other useful standards are:

- **AS2397 Safe Use of Lasers in the Building and Construction Industry**
- **AS/NZS1336 Recommended Practices for Occupational Eye Protection**

![Laser radiation signage](image-url)
The most likely effect from exposure to a laser or laser product is heating or burning. Therefore, the skin and eyes are most at risk. With high-power visible lasers, the blink reflex of the eye may not be adequate to provide protection. Some other hazards associated with operating lasers include:

- exposure to atmospheric contaminants from the process
- collateral radiation associated with the laser product; for instance, UV or IR radiation may be emitted from flash lamps
- electrical hazards
- cryogenic coolants that may cause burns.

### Exposure standards

It is outside the scope of this book to provide in-depth details with regard to the analysis of exposure to lasers, but the ACGIH TLV and AS/NZS2211.1 could be sourced for further detail. AS/NZS2211.1 gives the maximum permissible exposure limits.

### Radio frequency radiation

Radio frequency radiation can be divided into a number of areas based on the frequencies of radiation. The frequency ranges for RF radiation are shown below in Table 9.5.

The main health effects of exposure to radio frequency radiation are mainly thermal with the cornea and lens susceptible to frequencies between 1 GHz and 300 GHz. Human hearing may also be at risk of exposure. Another source of exposure that is less recognised is from ground level or airborne radar installations. The energy level can be measured as the power flux density (S), electric field strength (E) and/or the magnetic field strength (H). AS/NZS2772.1 has exposure limits for RF radiation.

#### Table 9.5 Frequency ranges for RF radiation

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Frequency classification</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHF</td>
<td>Extremely High Frequency</td>
<td>30–300GHz</td>
</tr>
<tr>
<td>SHF</td>
<td>Super High Frequency</td>
<td>3–30GHz</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
<td>0.3–3GHz</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
<td>30–300MHz</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency</td>
<td>3–30MHz</td>
</tr>
<tr>
<td>MF</td>
<td>Medium Frequency</td>
<td>0.3–3MHz</td>
</tr>
<tr>
<td>LF</td>
<td>Low Frequency</td>
<td>30–300kHz</td>
</tr>
<tr>
<td>VLF</td>
<td>Very Low Frequency</td>
<td>3–30kHz</td>
</tr>
<tr>
<td>ELF</td>
<td>Extremely Low Frequency</td>
<td>30–300Hz</td>
</tr>
</tbody>
</table>
Common sources of radio frequency fields include:

- monitors and video display units (3–30 kHz)
- AM radio (30 kHz–3 MHz)
- industrial induction heaters (0.3–3 MHz)
- RF heat sealers
- medical diathermy (3–30 MHz)
- FM radio (30–300 MHz)
- mobile telephones, television broadcast, microwave ovens (0.3–3 GHz)
- radar, satellite links, microwave communications (3–30 GHz)
- the sun (3–300 GHz).

Health effects

The type of health effect from exposure to radio frequencies will depend on its frequency. For instance, fields above 10 GHz are absorbed at the skin surface, with very little of the energy penetrating into the underlying tissues. However, if the fields are between 1 MHz and 10 GHz, they can penetrate exposed tissues and produce heating due to energy absorption in these tissues. Microwaves are a component of radio frequencies and occupy the spectral region between 300 GHz and 300 MHz.

The depth of tissue penetration with RF radiation depends on the frequency of the field and is greater for lower frequencies. Most adverse health effects that could occur from exposure to RF fields between 1 MHz and 10 GHz are consistent with responses to induced heating, resulting in rises in tissue or body temperatures higher than 1°C.

Radio frequencies can also interfere with the normal functioning of the body, with induced current densities that exceed 100 mA.m⁻². Other effects on the body from exposure to low-intensity RF fields, present in the living environment, have been reported; however, either they have not been confirmed by other laboratory studies or their health implications are unknown. Current scientific evidence indicates that exposure to RF fields is unlikely to induce or promote cancers.

Mobile telephones and towers

Since this book was originally published in 1999, research has continued into the short- and long-term health effects of mobile telephones and towers. Most research points to no substantiated evidence that living near mobile phone towers or using a mobile telephone causes any adverse health effects.

Since mobile telephones, as well as many other electronic devices in common use, can cause electromagnetic interference in other electrical equipment, caution should be exercised when using mobile telephones around sensitive electro-medical equipment used in hospital intensive care units.

Mobile telephones can, in rare instances, also cause interference in certain other medical devices, such as cardiac pacemakers and hearing aids. People using such devices should contact their doctor to determine the susceptibility of their products to these effects.

Extremely low frequency radiation

Extremely low frequency (ELF) radiation is most commonly 50 Hz radiation from electrical conductors. Since the electric fields from the ELF radiation will not penetrate the body, the main occupational health concern is associated with the magnetic field. Much media attention has been given to the use of electric blankets, hair dryers and arc welders due to the inconclusive effects of exposure to magnetic fields. Research tends to indicate that there may be a statistical relationship between increased childhood cancer rates and exposure to powerline frequency magnetic fields.
CONTROLS FOR RADIATION

The principles of control for radiation will depend upon whether it is ionising or non-ionising. With most forms of radiation the general strategy is to shield and distance the worker from the source through time and distance. The shielding material may be metallic (e.g. lead is frequently used for ionising radiation control), glass (e.g. window glass attenuates non-ionising radiation well, especially microwaves and UV radiation) or concrete. Workers who may be susceptible to the effects of radiation can be separated or isolated from the source. For instance, with ELF it is best to keep workers with metal surgical implants or cardiac pacemakers away from these sources.

Administrative controls such as worker rotation, monitoring of dose and training are also important in the overall scheme of risk control. Personal protective equipment such as sunscreen, protective eyewear and clothing should be worn to protect against UV and IR radiation. Some relevant standards include:

- AS/NZS1338.1 Filters for Eye Protectors — Filters for Protection Against Radiation Generated in Welding and Allied Operations
- AS/NZS1338.2 Filters for Eye Protectors — Filters for Protection Against Ultraviolet Radiation
- AS/NZS1338.3 Filters for Eye Protectors — Filters for Protection Against Infrared Radiation
- AS/NZS1336 Recommended Practices for Occupational Eye Protection
- AS1067 Sunglasses and Fashion Spectacles — Safety Requirements
- AS1067.2 Sunglasses and Fashion Spectacles — Performance Requirements.

PRESSURE

Working above or below atmospheric pressure is limited to a select number of jobs such as underwater diving. Exposure to pressure can occur during construction of bridges, rigging of heavy objects underwater, inspection of pipelines, cutting or welding underwater and aquatic scientific research activity and can affect recreational diving instructors.

From an occupational hygiene perspective, the hazards are categorised as hypobaric (low pressure) and hyperbaric (high pressure).

Hypobaric conditions occur where work is conducted at altitude. Some examples of occupational exposure include high-altitude construction and aviation. The main problem with this is the reduction in partial pressure of oxygen. The main health effects are:

- **Hypoxia** — this is due to insufficient oxygenation of the blood. The respiratory ventilation rate increases to compensate for the oxygen depletion. This reduces the workers’ ability to perform extended physical work and affects judgement.
- **Benign acute mountain sickness** — this occurs when a person rapidly ascends to an area of less oxygen. It generally resolves itself within three to five days, and is characterised by a group of symptoms including headache in the front part of the head.
- **High altitude pulmonary oedema and high altitude cerebral oedema** — these can become life threatening if not treated by rapid descent to a lower altitude.

Hyperbaric conditions are most often associated with underwater work. The main occupational health hazards associated with this type of work are:
• **gas toxicity** — this is due to the effect of oxygen and carbon dioxide inhaled at high pressures; the brain and lung can be damaged and judgement drastically impaired

• **decompression sickness** — this occurs due to the changing pressure and results in nitrogen bubbles in the body

• **trapped gas in the blood** — this is a painful condition where trapped gases are released into the tissues from the blood before the nitrogen is exhaled; many divers now use a mixture of helium and oxygen to minimise this occurrence

• **alternobaric vertigo** — uneven pressure stimulation of the balance mechanism in the ear due to unequal middle ear pressures or blockage of the Eustachian tube

• **dental and ear barotrauma** — dental barotrauma is caused by air trapped in a cavity beneath a filling; ear barotrauma can be in the external, middle or inner ear.

The AS/NZS2299 series can be used for advice on controls about occupational underwater diving operations. It includes requirements for personnel, diving procedures, equipment, compression chambers and compressed air supply. It also contains a useful segment on medical standards, medical examinations and reports, decompression tables, therapeutic recompression treatment, diver qualifications, employer and diver records, hand and lifeline signals and diving operations’ manuals.

For further information about diving safety, it may be worthwhile to contact the Professional Association of Diving Instructors (PADI). PADI is a diver-training organisation that establishes standards for diver training, trains and certifies instructors and provides information to its members. Otherwise, the best contact available Australia-wide is the Royal Australian Navy School of Underwater Medicine. The Diving Medical Officer should be able to provide a recent list of recompression facilities available throughout Australia and give immediate direction. In some States and Territories, the workplace health and safety regulatory authority may also have diving inspectors who are experts in diving safety and health.

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**SUMMARY**

Physical hazards such as pressure and radiation may present a significant risk to workers. Radiation can be either ionising or non-ionising. Ionising radiation includes \( \alpha, \beta, \gamma \) and X-rays. Non-ionising radiation or electromagnetic radiation consists of an electric and magnetic field.

Exposure to pressure occurs through specialised work and can be due to high or low pressure.

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**BIBLIOGRAPHY AND FURTHER READING**

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National Health and Medical Research Council 1987, *Occupational Standards for Exposure to Ultraviolet Radiation*, NH&MRC, Canberra
Standards Association of Australia/New Zealand 1992, *AS/NZS1338.3: 1992 Filters For Eye Protectors — Filters for Protection Against Infra-red Radiation*, Standards Australia/New Zealand, North Sydney
Chapter 10

Biological hazards

A biological hazard can be described as any micro-organism or material of biological origin that has the ability to cause illness. The body has several mechanisms for dealing with such invaders beginning with the first line of defence, the skin and mucous membranes. Should the agents enter the body, however, immunity (cellular and humoral) takes over, on a ‘locate-and-destroy’ mission. Chapter 2 outlined the role of the immune system in defending against foreign agents. Many plants and animals produce or store pathogenic micro-organisms. These can then be transmitted before a period of incubation and infection.

This chapter focuses on the meaning of biological and microbiological hazards, categories of biological agents and methods of transmission including vectors, direct transmission and reservoirs.

It will also outline the reservoirs, vectors and health effects of various types of occupationally related diseases caused by biological agents. The chapter will conclude with options for the control of biological hazards.

**HUMAN AND MICROBIAL INTERACTION**

Whether at work or play, we are not alone. Although we cannot see the tiny organisms or microbes surrounding us, very large numbers inhabit the surfaces of our bodies. Indeed, each individual person carries at least 10 000 times more bacteria than there are people in the world. While this might seem astounding, the presence of microbes does not necessarily spell trouble. The body has mechanisms to deal with microbial flora without compromising homeostasis. The surfaces of the body are the first line of defence. The characteristics of the skin and mucous membranes were identified earlier in Chapter 2. Acidity and antimicrobial substances such as lysozymes take much of the credit for protecting the body. Imagine working in a health care centre such as a hospital or nursing home. Each day workers are bombarded with various bacteria and viruses from ill patients. However, it is the body’s first line of defence that initially protects against such agents passing into the body. If the microbes were to enter the body, the second line of defence would take over. Immunity is responsible for a highly specific response to a foreign substance.

Immunisation can be humoral or cellular. Cellular immunity refers to various forms of white blood cells that move freely throughout the body, tracking and destroying foreign agents. Table 10.1 shows various cell types for cellular immunity. Humoral immunity can be achieved either through an innate system or by adapting to antibodies that have entered the body. These are outlined in Chapter 2.
Infection

If a microbial agent and a host form a relationship, an infection will occur. This is likely where the first line of defence is inadequate (e.g. due to a cut or abrasion to the skin) or the body’s immune system is unable to destroy the microbe. Certain drugs, injury or disease can contribute to the body’s inability to deal with microbial agents. Sometimes an infection may occur without a person realising its existence. Symptoms are a sign or change, showing that a substance has altered the body or its functions. A symptom of a biological infection might include a circular skin rash in the case of ringworm (a form of tinea caused by *Microsporum canis*), diarrhoea from a serious infection such as *E-coli* (*Escherichia coli*), or an asthmatic response from bird droppings (*Chlamydia psittaci*). Other times the infected person may be asymptomatic or show no symptoms.

Just as there may be a dose threshold for chemical substances to affect the body, biological agents must also reach a minimum infectious dose before infection will occur. After the microbe enters the body, it lies quietly but increases in number. This period of increasing growth is known as the incubation period. It may last from hours to years; however, once it reaches the critical level, infection occurs.

Health effects from microbial agents

The consequence of exposure to biological contaminants will depend on the route of entry, system of the body affected and nature of the individual agent. While symptoms may range from none to severe ill health, it is impossible to generalise about health effects from biological substances holistically. However, since most have passed through the first and second lines of defence, allergic responses are frequently elicited. Allergy or hypersensitivity are unwanted immune reactions that involve either antibodies (immediate hypersensitivity) or sensitised lymphocytes (cell-mediated hypersensitivity). Table 10.2 shows how allergic reactions are categorised into four groups.

From an occupational hygiene perspective, most hypersensitivities are Type I and IV.
Type I hypersensitivities occur where the body becomes sensitised to an allergen (i.e. pollen, animal hair or moulds). Allergic extrinsic alveolitis is a lung condition that is associated with exposure to such substances. It occurs when the immunoglobulins (antibodies) attack these antigens, causing symptoms such as asthma or allergies.

Type IV or delayed hypersensitivity shows effects some time after exposure to the antigen. This is due to the response of the macrophages by sensitised lymphocytes. Allergic contact dermatitis (from exposure to substances such as nickel, chromium or poison ivy) is an example of a Type IV delayed hypersensitivity.

**Transmission**

An important issue to consider with biological contaminants is the mechanism of exposure. Is the agent in the workplace due to normal operations or a by-product of the work? Has it been accidentally introduced from an outside source? How is it passed from one host or reservoir to another? Transmission describes the path that microbes take from the initial host (where they may multiply and grow in aggression) to the infected host. In some cases, a person or animal may be a reservoir for the agent, although they may not show symptoms. This means that their body is actually a ‘home’ for the microbe and it can be transmitted to others.

The most common routes of transmission of occupationally related biological contaminants are through:

- **direct contact with the microbe**
- **air**
- **water**
- **vectors.**

Direct contact might occur by touching an infected surface or person. For instance, a veterinarian delivering a calf that is infected with *Coxiella burnetii* could contract Q Fever; or cross-infection from one patient to another may occur in a health care setting. Airconditioning systems are renowned for the proliferation of airborne particles containing *Legionella pneumophila*, which could cause legionnaire’s disease. Infected drinking water could contain high levels of *Giardia lamblia*, causing giardiasis. Sewage workers may be exposed to pathogenic agents such as E-coli.

Vectors allow the movement of microbes. Some examples include lice, rodents and mosquitoes. Mosquitoes transmit blood-borne diseases such as dengue and Ross River virus. Louse-borne typhus has been associated with poor conditions and overcrowding. Rats’ urine

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**Table 10.2 Categories of allergic reactions**

<table>
<thead>
<tr>
<th>Type</th>
<th>Reason for effect</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Release of mediators like histamine to cause smooth muscle contraction and dilate capillaries</td>
<td>2–20 minutes</td>
</tr>
<tr>
<td>II</td>
<td>Reaction of antibodies with red blood cells (RBC)</td>
<td>4–10 hours</td>
</tr>
<tr>
<td>III</td>
<td>Inflammation due to activation of leukocytes which degranulate</td>
<td>2–10 hours</td>
</tr>
<tr>
<td>IV</td>
<td>Macrophages respond to sensitised lymphocytes many hours after exposure to the antigen</td>
<td>24–48 hours</td>
</tr>
</tbody>
</table>
in sugarcane fields has been associated with leptospirosis.

**CATEGORIES OF BIOLOGICAL AGENTS**

Micro-organisms can be classified into two main groups:

- **Prokaryotae** — or single-celled organisms that lack a true nucleus
- **Eukaryotae** — or multicellular organisms whose cells contain a true nucleus.

Prokaryotic organisms include bacteria, chlamydia, rickettsia and mycoplasmas. Eukaryotic organisms include plants, animals, algae (except blue-green algae), fungi, parasites and protozoan.

**Algae**

Algae are widely found in nature and contain chlorophyll and other pigments that provide their green or red appearance. From an occupational hygiene perspective, algae present a low risk to most workers. The exception to this is where water is polluted from the growth of many algae (blooms) which are then consumed.

**Animals**

The main types of biological agents that are categorised under the term animals include arthropods and helminths. Arthropods are joint-legged animals such as spiders, mites, ticks, centipedes, millipedes, bees, flies, crabs and crayfish. Some arthropods are merely mechanical vectors (for transferring a microbiological agent) while others allow multiplication of the bacteria or microbiological agent. An example of an arthropod-borne disease is Lyme disease (Borrelia burgdorferi) from ticks. Helminths can be further broken down into the platyhelminths and aschelminths. Platyhelminths (flatworms) have a flat or leaf shape, often with a head. They include the beef tapeworm (Taenia saginata), liver fluke (Fasciola hepatica) and pork tapeworm (Taenia solium). Aschelminths are round, elongated worms that have a complete digestive system. Diseases from intestinal worms include trichinosis (Trichinella spiralis) and hookworm disease (Necator americanus). The other types of aschelminth are the blood and tissue worms. The vectors for these worms are typically animals such as mosquitoes and flies.

**Bacteria**

There is an enormous variety of bacteria, although they all share the common characteristics of being prokaryotic cellular organisms. This often is where the similarity in structure and function of many bacteria ends.

Bacteria are divided into different divisions depending on their morphology, cell arrangements, oxygen requirements, motility and nutritional and metabolic properties. Their names consist of two part — the genus and the species.

Bacteria morphology or shape is categorised into three types: cocci (spherical), bacilli (rod) and spiral (spirilla and spirochaete). Cocci can be either individual cells or linked together to form a group of cells. Bacilli are shaped as rods or cylinders. Where the bacteria look similar to both a cocci and rod, they are named coccobacilli. Spiral forms of bacteria have a distinctive helical shape.

**Cell arrangements**

The main parts of bacterium are appendages (e.g. flagella, fimbriae and pili), surface layers, cytoplasm and special structure. Flagella are the propulsion mechanism of the cell. Fimbriae appear on gram-negative bacteria and adhere to other cells. Pili are involved in bacterial conjugation.
Bacterium can have several surface layers. Many have an outside layer (the capsule), a cell wall, plasma membrane and mesosomes.

A common description of bacteria refers to its response to a differential staining technique known as the ‘gram stain’. This results in categorisation as either gram-positive or gram-negative bacteria. While a full discussion of the reasoning behind this response is beyond the scope of this chapter, it should be said that the difference in the groups relates mainly to their cell wall construction.

**Oxygen requirements**

Some bacterial cells require oxygen for respiration (i.e. they are aerobic) while others function without oxygen (anaerobic). Oxygen requirements are another way of classifying bacteria.

**Motility**

The flagellum is the whip-like appendage attached to bacterium. Some bacteria have several flagella. Another mechanism of movement for the bacteria is gliding by the contracting cytoplasm.

**Nutritional and metabolic properties**

This classification describes whether the bacteria are able to photosynthesise or require nutrition from outside the cell. Some bacterial cells are able to form endospores. These are developed within the cell and are able to develop into a new organism if required.

**Chlamydia**

These are a type of eukaryotic organism that is actually parasitic. They are coccoid bacteria that range in size from 0.2 µm to 1.5 µm. They are not motile and do not require insects or ticks for transmission but can be transferred through interpersonal contact. They are known as obligate intracellular parasites since they are transmitted to a host where they obtain nutrients to survive. An example of chlamydia is Chlamydia psittaci which is found in bird droppings.

**Fungi**

Fungi are vegetative structures that require organic compounds for energy. They include moulds and yeasts, and are multicellular (except for yeasts). Moulds grow as long filaments of cells called hyphae.

Inhalation of some fungal antigens, such as Thermoactinomyces sacchari from mouldy sugarcane or Micropolysporis faeni and Thermoactinomyces vulgaris from mushroom compost, can cause extrinsic allergic alveolitis. Yeasts are usually round and larger than most bacteria. They are different from mould, in that they exist as individual cells.

**Mycoplasmas**

Mycoplasmas are bacteria that do not form cell walls. They are very small, ranging in size from 0.1 µm to 0.25 µm. The most significant human pathogen among mycoplasmas is Microplasma pneumoniae, which is the causative agent for primary atypical pneumonia.

**Parasites**

Technically, all viruses and many bacteria are parasites. These include protozoan, fungi, helminths and arthropods and are individually explained throughout this chapter.

**Protozoan**

Protozoan can exist as unicellular or multicellular organisms and can be divided into the following four groups based on their method of motility:
- mastigophora
- sarcodina
- sporozoa
- ciliata.

The mastigophora class has flagella and typically a long cell shape. An example within this category of protozoan is *Giardia lamblia* (which causes giardiasis, an intestinal infection). The sarcodina class includes amoebae, which are associated with abdominal complaints such as dysentery. Sporozoans cause diseases such as malaria and toxoplasmosis and are all parasites of animal hosts. The final class, ciliata, have short projections from the cell body.

**Rickettsias**

Rickettsias can reproduce only within a host cell, making them similar to viruses, but because their morphology and biochemical structure is similar to that of bacteria, they are classified as such. Rickettsias are rod-shaped bacteria (coccobacilli), ranging in length from 1 µm to 2 µm. An interesting feature of rickettsias is that they are transmitted to humans through insects and ticks. The exception to this is *Coxiella burnetii*, which causes Q Fever. Q Fever is often found where animal fluids, dust, wool or straw have been contaminated with the bacteria.

**Viruses**

Viruses are non-cellular structures with a diameter of around 20–200 nm. They consist of a nucleic acid centre, which is surrounded by a protein or protein and lipid coat. Viruses are obligatory intracellular parasites, which means they must have a living host cell to multiply. In order for the virus to multiply, it must invade the host cell and take over its metabolic machinery. This process changes the host cell and may result in its death. Some examples of viruses include influenza, human immunodeficiency virus (HIV) and the herpes virus.

**Zoonoses**

Zoonotic diseases are those acquired through contact with animals or animal products. The industries at particular risk include those involved in:

- **animal production and marketing** (e.g. farmers, meat processing, abattoirs)
- **health care** (hospital workers and cleaners, public health care workers, sewage workers)
- **research** (laboratory technicians involved in animal experimentation and testing, pharmaceutical researchers)
- **handling livestock** (veterinarians, horse trainers, farriers, stock workers)
- **pet industry** (kennel operators, bird breeders, pet store operators)
- **entertainment involving animals** (zoos, circuses and wildlife parks).

This section of the chapter will focus on individual zoonoses and provide a description of their nature, reservoirs, vectors and health effects.

**BACTERIAL ZOO NOSES**

**Anthrax**

Anthrax is also known as woolsorters’ disease or malignant carbuncle. In people, the disease is rare and can be caused by *Bacillus anthracis*. The cycle of transmission begins from an infected source (cows, goats or sheep), contaminated animal products (leather, pelts, bone meal, wool or fur) or spores in the air. It generally takes around two to five days for
incubation before symptoms on the skin, in the respiratory system or in the gastrointestinal system appear.

**Brucellosis**

There are six species of the genus *Brucella*. People are susceptible to the bacteria *B. melitensis*, *B. suis*, *B. abortus* and *B. canis*. The other two species are *B. neotoma* and *B. ovis*. The natural reservoirs of *B. suis*, *B. abortus* and *B. canis* are pigs (or swine), cattle and dogs, respectively. Goats and sheep are the natural hosts of *B. melitensis*. Workers are frequently infected either through consumption of infected meat or animal products or by inhalation of the bacteria from the animals, for instance, consumption of goats’ cheese or raw milk, or unpasteurised cows’ milk. It is also possible for vegetables that have been fertilised with infected excreta from these animals to transfer the bacteria, if eaten raw.

The most common occupational groups at risk are those exposed to the bodily fluids of infected animals, such as veterinarians, farmers, slaughtering yard personnel and abattoir workers. The main source of infection is in the foetus, afterbirth and vaginal discharges from cattle, swine, goats and sheep. Symptoms of the disease include headache, sweating, fever, muscular pains and depression.

**Camphylobacteriosis**

*Campylobacter* organisms live naturally in the gut of sheep, pigs, cattle and birds. The main species of occupational health significance are *C. jejuni* and *C. fetus*. Workers can become exposed to the bacteria *C. jejuni* through:

- **eating animals or animal products** (e.g. raw milk, birds handled in the kitchen and eaten without proper cooking)
- **drinking contaminated water**

C. *fetus* or *C. vibriosis* is quite uncommon and the mode of transmission is uncertain. Animals such as cattle and sheep are typically the reservoir, with either direct contact or food contamination suspected to be the cause of transmission.

**Glanders**

Glanders is a rare disease that is caused from *Pseudomonas mallei*. It manifests as pneumonia with ulcers appearing in the nostrils and pharynx. Although seen infrequently, the mortality rate is high. Solipeds (solid-hoof animals such as horses and donkeys) are the reservoir for the bacteria. Direct contact with workers (e.g. stablehands, horse trainers) can lead to the onset of the disease through skin contact or inhaling the aerosols.

**Leptospirosis**

Other terms for leptospirosis are Weil’s disease, canecutter’s fever or rice-field fever. It is frequently transmitted from rodent urine directly to workers or through contaminated water. Other hosts of the disease include cattle, pigs and domestic animals such as dogs. Therefore, people working with livestock, and workers walking through rice fields or sugar-cane paddocks in bare feet, are at risk of infection.

The bacterium of this disease is *Leptospira interrogans*. The symptoms of Weil’s disease begin with fever, headache, nausea and vomiting.

**Lyme disease**

Lyme disease was identified around the town of Lyme, Connecticut in the late 1970s. It is transmitted through the tick from the bacteria
Borrelia burgdorferi. After the tick bite, a red lesion appears on the skin. These lesions can be accompanied by a general feeling of unwellness with symptoms such as fever and a stiff neck. It can also lead to arthritis. A few people also develop meningoencephalitis.

**Mycoses**

Mycoses can be further broken down into:

- aspergillosis
- histoplasmosis
- zygomycosis.

Aspergillosis is relatively uncommon. The bacterium that causes the disease is Aspergillus fumigatus. The soil is usually the reservoir of the bacteria but the fungus is transmitted to people and animals through the air. Cattle and fowl are also susceptible to aspergillosis.

Histoplasmosis (also known as Darling’s disease or cavern disease) is spread from fungus (Histoplasma capsulatum). Both people and animals can acquire the disease from soil (the reservoir), usually during activities such as bulldozing, cleaning or demolishing rural structures (like chicken coops) and visiting bat caves. Rural and construction workers are mostly at risk.

Zygomycoses are diseases caused by fungi belonging to the Zygomycetes order. The fungi can produce a large number of spores. Transmission occurs through inhalation of these spores or contamination with the skin and inoculation. While animals such as horses, swine, dogs and cats can contract the disease, it is generally accepted that transmission between people and animals is unlikely.

**Salmonellosis**

Salmonellosis is a very common disease that is also known as an enteric infection. The symptoms typically include a sudden onset of fever, diarrhoea, nausea and vomiting within six to 72 hours after consuming infected food.

A serious side effect from salmonellosis is dehydration, due to the vomiting and diarrhoea. Eating contaminated food or water (similar to campylobacteriosis) usually transmits it.

**Tetanus**

Strictly speaking, tetanus is not a zoonotic disease because it is common to both humans and animals. Tetanus is caused by Clostridium tetani and is also known as trismus or lockjaw. The spores of the microbe are found in soils, on rust and also in the faeces of animals and people. The route of entry of the bacteria is usually through broken skin or wounds. Dog bites have been associated with tetanus, as have puncture wounds from rusty nails. The symptoms include painful spasms of muscles of the neck and face. The reflexes become exaggerated with a rigid abdomen.

**CHLAMYDIOSES AND RICKETTSIOSES**

**Avian chlamydiosis (psittacosis)**

The common name for avian chlamydiosis is psittacosis or ornithosis. The two main species of concern are Chlamydia trachomatis and C. psittaci. The disease is transmitted via the inhalation of C. psittaci which occurs in wild and domestic birds such as pigeons, turkeys, ducks and pet birds. Both the bird faeces and feathers are sources of infection. Symptoms show as respiratory illness (cough), sometimes accompanied with headache, fever, chills, sweating, anorexia and muscular aches.

**Q Fever**

Q Fever is caused by Coxiella burnetii and is also known as abattoir fever or pneumorickettsiosis.
The microbe is usually transmitted in aerosol form and the disease occurs frequently in abattoir or meat processing workers, especially on the kill-floor or hide area. The main source of infection is from domestic animals (e.g. cattle, sheep and goats) and their contaminated products (offal, afterbirth and foetus). Products such as hides and wool can also become involved in the transmission of the microbe. The incubation period of the disease ranges from a few weeks to a month. Symptoms, such as chills, sweating, anorexia, fever and malaise, show suddenly. Sometimes the person will also becomes nauseous and vomit.

**VIRUSES**

**Cowpox and viral haemorrhagic fevers**

Cowpox is believed to not occur in Australia. It has been isolated only in the United Kingdom and some of the western European countries. Viral haemorrhagic fevers (VHF) such as Lassa fever, Marburg fever and Ebola virus have not been identified in Australia.

**Influenza**

Influenza is an extremely common ailment that is spread through direct contact by droplets that penetrate the upper respiratory tract. It can also be spread by close contact such as in crowded workplaces or on public transport. Those with direct contact with the public, health care workers and teachers are at the greatest risk of infection. This virus has thousands of strains. From an occupational health point, influenza has been known to occur in animals such as swine, wild and domestic birds and horses. In 1997 in Hong Kong, Influenza A H5N1 (bird or avian flu) was discovered to affect people. The influenza presents with sudden and high fever, malaise, cough and sore throat. The outbreak saw the slaughter of more than a million chickens to prevent the spread of the disease.

**Measles**

Measles is caused from an RNA genome virus from the *Morbillivirus* genus. It has also been found in non-human primates such as monkeys, chimpanzees and orang-utans. Humans are the only known reservoir, and the disease is usually transmitted through airborne droplets. It causes fever, a cough, inflammation of the upper respiratory tract and reddish-brown spots. Health care workers caring for infected people with the disease may be at risk.

**Rabies**

Rabies is extremely rare in Australia. The rabies virus is an RNA virus that belongs to the *Lyssavirus* family. The animal hosts are chiefly carnivores (e.g. dogs, cats, foxes and skunks) and bats. Infection usually occurs from the bite of an infected animal. The disease incubates anywhere from two to eight weeks but it can be up to eight months. Initial symptoms of the disease include anxiety, malaise and increase in body temperature. As the disease progresses, respiratory muscles begin to spasm. Rabies can lead to death.

**PARASITIC DISEASE**

**Giardiasis**

Giardiasis or lambliaisis is caused by the protozoan, *Giardia lamblia*. The main animals at risk are cats, dogs and guinea pigs. The infection can be asymptomatic or show as diarrhoea, flatulence and intolerance of specific foods. While people are the main reservoir, the source of infection comes from faeces that contain the parasitic cysts. Transmission can occur by the oral–faecal route or by contaminated drinking water.
Hydatidosis

A small tapeworm called *Echinococcus granulosus* causes hydatid disease. It infects animals such as sheep, cattle, swine and kangaroos, resulting in the intestines of these animals becoming infested with the cysts.

When dogs consume the offal of infected animals, they can then pass on the disease to humans. Therefore, farmers, veterinarians and dog owners can be at risk. The health effects (to humans) from exposure include cyst growth in the liver and lungs. Unfortunately, these cysts can rupture, causing a leakage of fluid from the cyst or surrounding cysts. The disease can also interfere with the organ in which the cyst is attached.

Toxoplasmosis

The protozoan that causes this disease is *Toxoplasma gondii*. While this infection is quite common in humans, with about one-third of the world’s population possessing antibodies to the parasite, not all will possess symptoms of the disease. It is transferred to humans from domestic and some wild cats. These animals contract the infection by eating raw meat that is infested with cysts. People then become infected by eating raw or insufficiently cooked meat or through direct contact with cats. The major concern with toxoplasmosis is the damage to the human foetus.

Trichinosis

This disease results from a small nematode, *Trichinella spiralis*. The transmission cycle focuses around the pig and other animals such as dogs, cats and rats. After the animals eat meat that is infected with the larva, it lodges in the small intestine of the animal and reaches adult stage in a few days. The adults then hatch larvae. Larvae are able to cross the intestinal walls and are transported to the superior vena cava of the heart. From here, they are transported throughout the body.

Fungi

Ringworm

This ailment is also known as tinea or dermatomycosis. It is caused from species of *Microsporum* and *Trichophyton*. The condition occurs in the skin, hair and nails where the fungi causes inflamed lesions. Cats, dogs, cattle, horses and rats have all been linked with the spread of ringworm. It also can affect workers in laundries, veterinarians and their assistants, athletes and gymnasium workers.

Humans as Reservoirs

In many cases of microbial infection, people are responsible for transmitting a disease (or organism causing the disease) to one another. The cause, method of transmission and symptoms will be explained for a selected number of the ailments. Some examples of these types of diseases are:

- E-coli
- hepatitis A, B, C
- HIV
- multiresistant staphylococcus
- dipheria
- streptococcosis
- tuberculosis.

E-coli

*Escherichia coli* or E-coli is an enterobacterium that causes stomach complaints such as ‘Delhi belly’, ‘travellers’ diarrhoea’ and ‘tropical trots’. It is passed through the oral–faecal route. Occupations at risk include health care workers, teachers and child care centre workers. Poor hygiene at
food outlets may also place other workers at risk.

**Hepatitis A, B, C**

The hepatitis virus affects the liver. There are at least six commonly known strains of hepatitis (A–F). This section describes hepatitis A, B and C.

Hepatitis A is a very infectious disease that is usually asymptomatic. It occurs where water has been contaminated with the virus, usually in conditions of poor hygiene.

The more serious hepatitis B is transmitted through the blood or bodily fluids. Most people who become infected do not progress to the full development of disease; although they do carry the virus forever. For about 10 per cent of those infected with hepatitis B, the disease progresses and multiplies, causing a cirrhosis and carcinoma (cancer) of the liver. Workers at risk of this disease include health care workers, workers in the sex industry, cleaners who may be exposed to contaminated hypodermic needles and even police officers who may be stabbed with an infected needle.

Hepatitis C usually occurs in people who have received contaminated blood transfusions.

**HIV (human immunodeficiency virus)**

This virus has caused worldwide fear and pandemonium since its identification in the early 1980s, although significant progress has been made to treat the disease since this time. There are actually two HIV viruses — HIV1 and HIV2. While they produce the same disease (acquired immune deficiency syndrome or AIDS), the speed and aggression of the progression of disease is the differentiating factor. The HIV virus is a fragile virus that can survive outside the body for only a limited time. For this reason, most transmission occurs via direct contact through blood or bodily fluids. It is believed that the viral cells attack the white blood cells of the body, preventing the development of an effective immune response.

When the body’s immune system is unable to cope with this degradation, normally innocuous microbes will begin to cause infections. The other effect of HIV is the development of malignancies. This indicates that the virus is progressing to an ‘AIDS-related complex’. The occupations most at risk from this disease are unprotected sex workers and health care workers such as doctors, surgeons, nurses, paramedics and dentists.

**Multiresistant staphylococcus**

As the name suggests, members of the *Staphylococcus* genus are spherical shaped cells. For occupational health, *S. aureus* is the microbe that is of most concern. People at risk of such infections include those with lower immunity such as diabetics, those with respiratory viral infections such as influenza or measles and those receiving immunosuppressive drugs. *S. aureus* is the microbe behind the production of boils or abscesses and toxic shock syndrome. It is also notorious for becoming resistant to drug therapy. Therefore, many antibiotics are ineffective for treating staphylococcal infections.

**Streptococcosis**

Streptococcosis is caused by the genus *Streptococcus*. The main pathogen in humans is *S. pyogenes* which frequently causes sore throats and tonsillitis. This is known as Group A streptococci. Group B streptococci (*S. agalactiae*) are particularly hazardous to young children, with meningitis a characteristic of the infection. Group C streptococci (*S. equi*) are rare in humans. Transmission of streptococcal infections usually occurs from person-to-person.
**Tuberculosis**

Tuberculosis is caused by mycobacteria, *Mycobacterium tuberculosis* or *M. bovis*. It is relatively uncommon in Australia. *M. tuberculosis* can be transmitted directly from one carrier to another or indirectly through dusts or other vectors. The mycobacteria are implanted in the lungs. Tuberculosis caused by *M. bovis* usually occurs from the ingestion of infected, unpasteurised milk. Once consumed, the mycobacteria become implanted in the gut. Therefore, dairy farmers may be at risk.

**Symptoms of SBS**

Although the symptoms associated with SBS are often broad-based and non-specific, they can be divided into various categories:

- **dry symptoms** — stuffy nose, dry throat, dry skin
- **allergic symptoms** — runny or itchy nose, watery itchy eyes
- **asthma** — tight chest
- **general symptoms** — lethargy and headache, nausea, reduced memory.

**The Australian perspective**

In Australia, studies of SBS have been based on domestic dwellings and workplaces. They have considered the effects of formaldehyde in caravans and mobile dwellings, nitrogen dioxide (NO₂) from kerosene or gas space heaters and carbon monoxide (CO) from gas cooking or where a garage is attached to the domestic dwelling. Chapter 6 described the health effects from exposure to these gases. In Western Australia, radon has been investigated. Places where smoking is permitted have a higher concentration of polycyclic aromatic hydrocarbons.

**Physical factors to consider with indoor air quality**

The main factors that will affect the quality of air inside a building are the contaminants that are generated, combined with the physical conditions. Temperature, humidity and air movement can contribute to a general feeling of discomfort. It is also important to consider that comfort is a largely individual perception. Optimal humidity ranges indoors are between 40 per cent and 60 per cent. Below a relative humidity of 20 per cent, the skin becomes dry and mucous membranes feel dry and itchy. If the relative humidity rises above 80 per cent,
this may allow fungal and bacterial contamination to become more prevalent. Air movement can also affect an occupant’s comfort. Air movement near the feet gives a feeling that the area is draughty.

**Contaminants**

The main contaminants that contribute to inadequate indoor air quality and may affect the prevalence of SBS can be divided into ten main sections:

- asbestos and fibreglass
- carbon monoxide
- electromagnetic radiation
- endotoxins and mycotoxins
- volatile organic compounds (VOC)
- environmental tobacco smoke (ETS)
- house dust mites
- *Legionella* organisms and pollens
- radon
- other chemical products.

Some of these are discussed in this chapter. Others are described according to the nature of their hazard in other chapters of this book.

**Environmental tobacco smoke**

Cigarettes, cigars and pipes emit a constantly changing mixture of particulate and gas. This is known as environmental tobacco smoke or ETS. ETS consists of both the sidestream and mainstream smoke.

While the constituents of the sidestream and mainstream smoke may be qualitatively similar, quantitatively they are rather different. Fresh ETS consists of a particulate–gas distribution that is predominantly in the gas phase. The median particle diameter for fresh ETS is 0.15–0.32 \( \mu \)m. Some examples of the chemicals that are released are:

- nicotine
- pyridine
- mysomine
- most nitrogen-containing volatile compounds
- mutagenic compounds.

As ETS ages, its chemical and physical characteristics change significantly. Small particles coagulate to larger ones and NO\(_x\) is converted to organic nitrogen compounds. ETS was declared a potential human carcinogen in the United States by NIOSH in June 1991. This decision was based on the well-established health risk of tobacco smoking, comparison between sidestream and mainstream smokes and epidemiological studies of nonsmokers exposed to ETS.

NIOSH recommended that ETS should be eliminated from the workplace by total banning, education programs about the health effects and offering smoking cessation programs and incentives to stop smoking. It also recommended isolating smokers through physical separation and separation of ventilation systems. Since this time, Australian workplaces and public places have also restricted smoking due to the effect of passive smoking on other people.

More recently in Australia, State governments have introduced legislation that eliminates smoking in public places where food is consumed and the area is enclosed. While the definition of an ‘enclosed space’ differs between States, the general principles of not permitting cigarette smoking in such areas prevails.

**Radon**

Radon is formed through the decay of \(^{238}\)uranium through \(^{228}\)radium to \(^{222}\)radon. During this process alpha (\(\alpha\)) rays are emitted through the decay into a series of solid radioisotopes (radon daughters). The radon daughters diffuse into the air from rocks and soils and may dissolve into surrounding water. Radon and daughters are responsible for an
excess of lung cancers in many underground miners and are present in almost all buildings. Radon enters the buildings via pressure (the gas is driven through the soil through construction faults) and volatilisation of radon dissolved in water. Some factors that affect radon entering the building are:

- **soil properties** (radon content and soil permeability)
- **presence of construction faults**
- **meteorological factors** (changing barometric pressure, wind speed and direction and rain)
- **devices exhausting to outdoors** (such as exhaust fans and fireplaces).

**House mites**

It is estimated that there are one to two million house dust mites in the average bedroom in Australia, especially among and around the bed sheets and mattresses. The droppings from these mites may produce allergic problems such as asthma. Offices using or storing large quantities of paper (this includes libraries) can also find paper mites in the environment. These burrow beneath the skin, causing a rash and itchiness.

**Volatile organic compounds (VOC)**

Formaldehyde is a common contaminant of indoor environments and is an example of a VOC that could be released from carpets, furniture and fittings. VOC may give rise to irritation of the mucous membranes of the eyes and respiratory tract. Formaldehyde is a colourless gas with a pungent smell and very soluble in water. Urea-formaldehyde resin is used in carpet backings, floor coverings and foam insulation used as a building insulation. Urea-formaldehyde and phenol-formaldehyde resins are used as glue for plywood and as a component of particle board.

Formaldehyde may be released due to unreacted formaldehyde ‘off-gassing’ or decomposing. Its release depends on the age of installation, specific source, temperature and humidity. The half-life of formaldehyde in new homes with particle board and plywood can be up to five years.

**Legionella organisms and pollens**

*Legionella pneumophila* is a bacteria that occurs naturally and in reservoirs such as cooling towers of buildings. It can cause legionnaire’s disease and pontiac fever. Legionnaire’s disease manifests as a form of pneumonia and has a fairly high mortality rate, while pontiac fever is a mild, non-pneumonia disease that is non-fatal.

Legionnaire’s disease is contracted by inhaling contaminated water droplets. The incubation period is usually three to six days. Males are three times more at risk than females, although the most vulnerable groups are:

- **those aged 40 to 70**
- **smokers**
- **alcoholics**
- **cancer patients**
- **diabetics**
- **kidney disease patients.**

The mortality rate is 10–20 per cent. The most likely source of infection of legionnaire’s disease is through circulating water systems such as cooling towers or industrial cooling systems. Hot and cold water services (including water storage tanks, filters, pipe work and disseminating shower spray heads) may also harbour the bacteria. Figure 10.1 shows an example of a cooling tower that is found at a power station. The circulating water is regularly checked for the organism.
Endotoxins and mycotoxins

Endotoxins are produced by gram-negative bacteria, and mycotoxins by fungi. It is still not clear how much ill health can be attributed to these organisms in the indoor environment.

Other chemical contaminants

This category includes ozone (which may be emitted from photocopying, UV lamps, laser printers and ionisers) and oxides of sulphur. Chapter 6 described the health effects of exposure to ozone and sulphur dioxide.

Investigating the indoor air quality issue

When investigating an indoor air quality issue, it is important to begin with an initial survey to:

- identify signs and symptoms of ill health
- investigate the ventilation system
- survey the pattern of occupancy and complaints
- generally discuss the nature of problems.

Some preliminary measurements of temperature, humidity and airflow pattern may also be useful. A detailed questionnaire may be utilised for a large workforce or at large premises, to enable collation of information. This should then be followed by a detailed site survey (although this will depend on the results of the initial survey).

A detailed site survey will involve:

- measuring ventilation
- obtaining detailed information about the temperature, humidity and carbon dioxide levels
• measuring for individual contaminants
• sampling for airborne microbial contaminants and those in reservoirs or on surfaces
• identifying possible sources of contaminants (both indoors and outdoors).

The analysis of data will depend upon the appropriate guideline or standard that has been chosen. The data may be analysed by comparing conditions between indoor and outdoor situations or correlating the data with symptoms or complaints. Some monitoring equipment is available to help conduct an indoor air quality assessment. The equipment typically monitors carbon dioxide, temperature and relative humidity but may also be fitted with detector, sorbent or filter tubes to measure other pollutants.

### ORGANIC DUSTS

Exposure to many organic dusts can cause occupational asthma. The symptoms of occupational asthma include a wheeze (although not always), a reduction in the peak expiratory flow rate (PEFR) and breathlessness. It is known as a reversible airways obstruction.

Some examples of organic substances that are common causes of occupational asthma include animal proteins, coffee beans, wheat flour, rye flour, tea and insect proteins. Organic dusts can also result in extrinsic allergic alveolitis (a Type III mediated hypersensitivity reaction). Some causes of occupational extrinsic alveolitis are provided in Table 10.3.

#### Byssinosis

Exposure to cotton, flax, hemp or sisal dust can lead to byssinosis after several years of exposure. Thus, textile workers are most at risk. The disease is graded according to its severity and symptoms range from occasional tightness of the chest on the first day of the working week to permanent breathlessness every day with a cough.

#### Mill fever and weavers’ cough

Mill fever historically occurred in mills that were processing cotton, flax or hemp. The dust is suspected of containing endotoxins, which cause a mild fever. The worker may also have a cough. Weavers’ cough occurred after workers handled cotton yarns that had been treated with flour paste or tamarind seed extract. The fungi from these were believed to cause the asthmatic response.

### Table 10.3 Causes of occupational extrinsic alveolitis

<table>
<thead>
<tr>
<th>Disease or condition</th>
<th>Source of dust</th>
<th>Causative agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer’s lung</td>
<td>mouldy hay</td>
<td><em>M. faeni</em>, <em>T. vulgaris</em></td>
</tr>
<tr>
<td>Bird fanciers’ lung</td>
<td>bird faeces and feathers</td>
<td><em>C. trachomatis</em>, <em>C. psittaci</em></td>
</tr>
<tr>
<td>Bagassosis</td>
<td>mouldy sugar cane</td>
<td><em>T. sacchari</em></td>
</tr>
<tr>
<td>Mushroom workers’ lung</td>
<td>mushroom compost</td>
<td><em>M. faeni</em>, <em>T. vulgaris</em></td>
</tr>
<tr>
<td>Malt workers’ lung</td>
<td>mouldy malt and barley dust or hair particles and urine</td>
<td><em>A. clavatus</em>, <em>A. fumigatus</em></td>
</tr>
<tr>
<td>Animal handlers’ lung</td>
<td>mould dust</td>
<td><em>P. casei</em></td>
</tr>
<tr>
<td>Cheese washers’ lung</td>
<td>fish meal dust</td>
<td>fish proteins</td>
</tr>
<tr>
<td>Fish meal workers’ lung</td>
<td>cotton</td>
<td><em>A. cloacae</em></td>
</tr>
<tr>
<td>Mattress makers’ fever</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Organic dust toxic syndrome**

This general term is given to illnesses where the symptoms are similar to that of allergic extrinsic alveolitis, except there is no long-term damage to the lung. It has been reported in farmers who handle moulding hay, grain silo workers and sewage treatment workers.

**HIGH-RISK INDUSTRIES**

As we would expect, the industries most at risk of exposure to biological agents are those where workers encounter infected people, animals or carriers of microbes. This encompasses a broad range of occupations ranging from people with constant contact with the public to those involved in biomedical laboratories. The following list illustrates the breadth of potential exposure of workers:

- health care workers in infectious wards of hospitals such as nurses, doctors and surgeons
- workers in nursing homes, day care centres or other similar institutions
- cleaners in high-risk workplaces such as hospitals, nursing homes, public toilets and parks
- veterinarians and their assistants
- farmers and their families
- food processing workers, especially smallgoods and abattoir workers
- research laboratories with highly pathogenic organisms
- biomedical laboratories testing bodily fluids (e.g. blood, urine).

**MONITORING TECHNIQUES AND COUNTING**

There are several reasons for sampling the work environment for microbial agents. Firstly, sampling will identify the presence and nature of potential biological hazards. As an example, office workers may be concerned about the quality of air in the ventilation system or perhaps an animal has died unexpectedly and the cause of the death is sought.

Secondly, identification of the level of risk to workers or the public may be required. This can be determined by measuring the concentration of organisms and comparing the result with a standard.

Thirdly, where biological agents are integral to a process (e.g. pharmaceutical, winemaking and brewing industries), it may be necessary to ensure the concentrations of organisms are maintained within a specified window or range.

The main methods of collecting samples are from air, liquids or surfaces. Beginning with air sampling, there are three main techniques that are used:

- inertial collection
- filters
- precipitators (thermal and electrostatic).

**Inertial collection**

This technique allows microbes to be collected by either impacting onto a surface or impinging into a liquid. The liquid or surface media must be especially suitable for this type of collection. It is usually agar with nutrients that will ensure the viability of the microbes for incubation and counting. Another type of medium is nutrient broth. The medium on which the microbe grows is dependent upon its individual requirements. Inertial collection can be conducted in a number of ways:

- settling plates
- impingers
- impactors
- centrifugal samplers.
Settling plates

Settling or settle plates are the simplest form of sampling. An open Petri dish is filled with a nutrient agar and left in the workplace for a period. Microbes drop onto the agar due to gravity (Figure 10.2).

After a suitable time, the dish is closed and sealed. It is promptly sent to a laboratory for incubation, identification of specific microbes and counting. Counting of microbial colonies should be left to a microbiological laboratory. Special care is required in the incubation and identification of microbial agents. Most are pathogenic.

Impingers

Just as in the liquid impingers used in gas sampling, air passes through a slit or jet in the impinger. It is then caught in the liquid, which is later analysed at a microbiology laboratory. Most impingers can sample particles with a diameter as low as 0.5 µm. The impinger must be connected to a sampling pump of known flow rate to sample a particular volume of air through the medium.

Impactors

A cascade impactor can divide the collected sample into different ranges of particle sizes. After the sample has been collected, it can be directly examined under a microscope or washed off and plated on a nutrient medium for counting and identification.

Centrifugal samplers

Several types of centrifugal samplers are available to sample for microbial agents. A cyclone separator such as the centrifugal air sampler shown in Figure 10.3 allows air to enter into and out of the unit through a port at the top of the instrument. Sampling can be
conducted from 30 seconds to eight minutes. The agar strips are then sealed for identification and counting of microbes.

**Filters for biological sampling**

The most important consideration in filtration sampling of biological contaminants is the particle size. In most cases the nominal pore size used in dust sampling will be too large to collect microbial agents efficiently. Collection of some vegetative micro-organisms that need to be kept moist to remain viable is not possible using filtration sampling.

**Electrostatic and thermal precipitators**

These devices are used less frequently in Australia. Electrostatic precipitators place a charge on the microbe to allow it to be attracted to an electrode of the opposite polarity. The charged particles are then deposited onto an agar surface or liquid. The advantage of this form of sampling is its incredible efficiency (around 100 per cent). It is also superior in collecting sub-micron particles. Thermal precipitators also find application in collecting sub-micron particles although not for viable biological particulate.

**Surface sampling**

In some cases, it may be appropriate to collect a sample directly from the surface of a bench, desk or workstation. There have also been some cases of indoor air quality checks involving cutting a section of carpet from an office and sending this for analysis. With all types of surface sampling, this technique should be used as an indicator of the presence of microbes. It is not necessarily an exposure quantity.

Contact slides are used to determine microbial contaminants on equipment and surfaces, microbial loads of personnel and
efficiency of disinfection measures. A flexible culture media carrier ensures contact with curved or irregular surfaces.

**Liquid sampling**

If a microbe is water-borne (e.g. air cooling tower, metal cutting lubricant) it may be more appropriate to directly sample from the liquid. This can be accomplished in two ways:

- **dip slides**
- **membrane filtering.**

Dip slides are essentially a paddle coated on both sides with a different microbiological media. The dip slide can be dipped into a liquid or the liquid can be streaked onto the paddle. After incubation, the growth on the paddle is compared with a concentration chart to determine the approximate number of organisms per millilitre of liquid.

Filtration sampling is mostly conducted using membrane filters. The pore sizes range from 0.025 µm to 8 µm. A pore size of 0.22 µm is usually adequate for collecting bacteria. The filter is usually placed directly onto agar medium after filtering. It is then incubated and organisms identified and counted.

**Table 10.4 Classifying biological agents**

<table>
<thead>
<tr>
<th>Risk group</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low individual and community risk</td>
<td>Acetobacter sp.</td>
</tr>
<tr>
<td>2</td>
<td>Moderate individual risk, limited community risk</td>
<td>S. aureus, Toxoplasma gondii</td>
</tr>
<tr>
<td>3</td>
<td>High individual risk, limited community risk</td>
<td>Coxielle burnetii, Histoplasma sp.</td>
</tr>
<tr>
<td>4</td>
<td>High individual and community risk</td>
<td>Ebola virus, Lassa virus</td>
</tr>
</tbody>
</table>

**CONTROLS FOR BIOLOGICAL HAZARDS**

The adoption of suitable control methods to minimise the risk associated with biological hazards will depend upon their source, route of entry, transmission path and nature of exposure. Two useful resources are AS/NZS3816 and AS/NZS2243.3. These provide guidance on managing both microbial agents in laboratories and in clinical and related waste. The Australian National Council on AIDS has also released a document about infection control.

AS/NZS2243.3 classifies infective microorganisms into four risk groups. These are shown in Table 10.4.

The main principles for reducing the risk from biological agents are:

- **elimination or substitution of the hazardous agent**
- **ventilation** (e.g. safety cabinets, glove boxes)
- **isolation of the person or microbe** (e.g. separate laboratories for highly pathogenic substances, isolate infectious patients and animals)
- **administrative controls** (universal precautions, standard precautions, cleaning, spills management, sterilising instruments and equipment, immunisation and health surveillance)
• **personal protective equipment** (uniforms, gloves, eye wear, face shields, respirators, gowns).

**Ventilation**

Ventilation is most appropriate in extremely high-risk workplaces such as hospitals and laboratories. There are many types of ventilation systems that can be used to contain aerosol microbes. It is therefore important to consider the pathogenicity of the organism being controlled, the amount of aerosol that could be released, practicability in installing the system and immune status of the workers. The three main types of biological safety cabinets are:

- **open hoods**
- **hoods with restricted access**
- **closed hood (accessing the hood through sealed gloves).**

An open hood is suitable for low-risk pathogens. Air is drawn into the hood and sterilised before discharge. Hoods with restricted access are similar to the open hood, except the space available for entry is limited. The limitation of these hoods lies in their efficiency in maintaining a sufficient capture velocity. If people walk in front of the hood or the sash is not fully closed, microbes could easily escape into the workroom.

AS2252.1 and AS2252.2 describe the performance and construction requirements for biological safety cabinets. Biological safety cabinets are divided into three classes. Classes I and II are suitable for micro-organisms from risk groups two and three, where the work creates a significant amount of aerosols (from AS/NZS2243.3). Class III biological safety cabinets have been developed for work with organisms from risk groups three and four.

Since the air is filtered before being released to the environment, it is important that the filtration devices are suitable for the microbial contaminant. High efficiency particulate (HEPA) filters or electrostatic filters are often found in these systems. For higher efficiency, a series of filters may be installed. Class I biological safety cabinets should operate with an incoming air velocity between 0.5 m.s\(^{-1}\) and 0.8 m.s\(^{-1}\).

The closed hood or glove box allows entry only through sealed gloves. Air passes into the ventilation system through a separate inlet. A negative pressure is maintained inside the hood to ensure that any leaks are directed into the system. The air is also sterilised before it leaves the cabinet.

**Isolation**

Removing or isolating hazardous work areas, reservoirs or carriers of the microbiological agent should be used in conjunction with other control techniques. For instance:

- **isolation of animals from the herd in a separate paddock or stable**
- **strict isolation of infectious patients in hospitals with restriction of visitors without adequate personal protective clothing and adopting administrative controls**
- **exclusion of sick children from day care centres or similar institutions**
- **removal of ill animals from public display or contact in zoos, wildlife parks and circuses**
- **separation of high-risk laboratories from low-risk areas and connection to an alternative ventilation system**
- **adequate drainage should be provided in farm areas such as piggeries, to isolate waste and effluent**
- **raising of pigs and cattle separately to prevent cross-infection**
- **keeping dogs away from animal carcasses that could be infested with cysts (hydatid disease)**
• destroying birds infected with psittacosis and quarantine of birds being treated.

Administrative controls

Administrative controls are by far the most commonly taken approach in dealing with microbiological hazards. The aim is to prevent the transmission of infection using the philosophy that for infection to spread, it requires a source, susceptible host and mechanism of transfer.

Universal and standard precautions

In Australia, universal precautions involve treating all blood and body substances as potentially infectious. Although, due to its ambiguity in definition with the US term, the notion of standard precautions has become more widely used in Australia. Standard precautions are essentially work practices that include:

• washing and drying hands before and after contacting patients
• use of protective barriers such as gloves, gowns, masks, eye shields and plastic aprons
• correct handling and disposal of infectious wastes or contaminated sharps
• use of aseptic techniques
• precautions with both fresh and dried blood and other body substances, including saliva.

Hygiene

Hygiene is linked with universal and standard precautions, although it is considered independently for the control of zoonotic diseases. Some examples of appropriate hygiene practices include:

• preventing the spread of infected aerosols or dust from cattle that may be infected with Coxiella burnetii
• burning or burying of infected placental and birth material from cattle that may be infected with C. burnetii
• eradication of rats and mice, especially in sugarcane fields prior to harvest, to prevent leptospirosis
• banning smoking or eating in meat processing areas
• treating cuts and abrasions promptly and ensuring these are covered with a water-resistant bandage
• disinfecting trucks carrying animals to abattoirs
• carefully handling animal offal that is suspected of carrying disease, especially the uterus and udder
• avoiding the consumption of raw or unpasteurised dairy products and raw meat to prevent campylobacter and salmonella infections
• no-touch techniques in microbiology laboratories
• avoiding use of mouth pipettes.

Sterility

Sterility can be related to both human-borne infections and zoonoses. Sterilisation of instruments and equipment can be achieved using steam sterilisation (autoclaving) or chemical sterilisation. Sterilisation using only hot water should be avoided, as all bacterial spores are not killed. Some other applications of sterility include:

• steam sterilisation under pressure at 121–134°C
• dry heat at 160°C or higher
• ethylene oxide sterilisation
• low-temperature hydrogen peroxide plasma sterilisation.
Some workplaces use heat-sensitive tape that changes colour once the optimal temperature for sterilisation has been reached and maintained for a long enough period.

**Vaccination**

Vaccination is an artificial way to acquire immunity. Today there are many vaccines available to immunise people. The antigen is usually injected into the body where it builds antibodies. Some applications of vaccination to protect against biological hazards include vaccination of:

- animals for diseases such as leptospirosis
- health care workers for hepatitis A and B
- workers in the public domain for several strains of influenza
- workers in abattoirs for Q Fever.

**Needle-stick and sharps**

Handling of needles and sharps requires special care. The main controls that are suggested include:

- provision of sturdy gloves such as leather gloves for cleaners who may be cleaning public toilets or gardens where needles are left
- provision of tongs or other devices to ensure the sharps are not touched
- mechanical cleaning of sharps in dental and hospital settings
- containment and disposal of sharps in receptacles that comply with AS4031 and AS/NZS4261
- maintaining records of accidents and reviewing the circumstances surrounding the incidents to reduce the frequency of occurrence.

**Labelling**

Biohazardous waste has a designated symbol. Any biohazardous material should be appropriately labelled and sealed for collection by approved collection agencies. The colour scheme for the symbol is either a black symbol on a yellow background, as required in AS1319, or an orange-red symbol on a background colour whose contrast makes it clearly defined. Biohazardous waste must not be thrown into normal garbage. The health departments in Australian States and Territories regulate the labelling and disposal of biohazardous waste.

**Training**

It is important that people who may or do come into contact with biological agents are aware of the hazard associated with the exposure. They should be trained on the symptoms of ill health and the organisation’s policy and procedure for dealing with an exposure to the agent. Workers should also be aware of the method for handling and disposing of biohazardous waste.

**Personal protective equipment**

While personal protective equipment does lie at the base of the hierarchy of control, it should still be utilised by those exposed (or potentially exposed) to biological hazards. The types of PPE may include:

- gloves
- eye and face protection (e.g. face shields, goggles)
- masks or respirators (P2 for bio-aerosols)
- gowns and aprons
- adequate footwear.

Chapter 13 provides further detail about the selection and use of personal protective equipment.
SUMMARY

Biological hazards, while not at every workplace, can present a high risk in certain situations. A biological hazard is a micro-organism or material of biological origin that has the ability to cause illness. Biological hazards may be human-borne or animal-borne. They can also be transmitted directly either through air, water or vectors.

Controls for biological hazards should follow AS/NZS3816 and AS/NZS2243.3.

BIBLIOGRAPHY AND FURTHER READING

National Health and Medical Research Council 1996, *Infection Control in the Health Care Setting*, NH&MRC, Canberra
Standards Association of Australia 2002, *AS2252.1: 2002 Biological Safety Cabinets (Class I) for Personnel and Environmental Protection*, Standards Australia, North Sydney
Ergonomics is a multidisciplinary field that is closely linked on many fronts to occupational hygiene. By definition, ergonomics links ‘work’ with the individual worker, to achieve an optimal operating interface or relationship. Ergonomics deals with physical stressors and with cognitive or psychological factors that can contribute to risk in the workplace.

This means that social, work and physical elements are considered when evaluating ergonomic hazards. Similarly, the physiology of the body, including effector and sensory organs and processing mechanisms, must be taken into account when assessing risk to workers.

Since a comprehensive discussion of ergonomics would require an entire textbook, this chapter aims to provide an introduction to the practice of industrial ergonomics and human factors. Its focus concentrates on methods of assessment of manual materials handling tasks, biomechanics and the physical environment. Discussion is also provided about issues such as shift work and occupational stress.

SOME DEFINITIONS OF ERGONOMICS

Before attempting to define ergonomics, it is important to recognise that ergonomics is a widely used term. The term ergonomics is derived from the Greek *ergon*, meaning work, and *nomos*, the study of. The principles of ergonomics that take into account the physiological and cognitive abilities of the users or workers are incorporated into most products that we consume or use. For instance, motor vehicle designers must consider the reach abilities of a range of drivers. Machine interfaces such as automatic teller machines (ATM) must be easy to use for ages ranging from early teens to the elderly. A good ergonomic design will also consider the social and biological characteristics of the users. In essence, ergonomics is a science that combines peoples’ abilities with appropriate designs. Some of the professions that are frequently involved in the field of ergonomics are human resource personnel, psychologists, physiologists, engineers, safety practitioners, sociologists, physiotherapists and medical practitioners.

Ergonomics encompasses issues such as:

- **muscular work and control of movements**
- **work efficiency and process design**
- **the problems of body size (anthropometry)**
- **heavy work and handling loads (manual materials handling)**
- **skilled work**
- **the person–machine interface**
- **mental activity, stimulus and fatigue**
There are several other names for ergonomics. The term ‘human factors’ is a US term and is often used instead of ergonomics. It considers the interaction between humans and products, equipment, facilities, procedures and the environment. 'Human engineering' is referred to less frequently since it conjures an image of a lack of sensitivity to the individual. Psychologists who study the cognitive demands of people in relation to work use another term, 'engineering psychology'. Again, this is probably not the best term and so ‘cognitive ergonomics’ is used in this chapter. Some useful Internet sites related to ergonomics are shown below.

www.ergonomics.org.au  
www.iea.cc  
www.ergonomics.uq.edu.au

MUSCULAR WORK

Muscular work is concerned with the:

- strength of muscles  
- time taken to fatigue muscles  
- isolation of specific muscles for movement and action  
- static and dynamic muscular loads  
- limitations to muscular work.

During the period 1994–95, a study by Straker (1998) of Australian workers’ compensation data suggested that ‘body stressing’ accounted for 34.3 per cent of compensated injuries in males and 47.1 per cent in females. More than half of these injuries were due to lifting, carrying and putting down objects. One-third involved other manual handling.

The physiology of the muscular system is outlined in Chapter 2. Muscles consist of motor units that contain thick and thin contractile proteins (myofilaments). These proteins slide past one another, enabling the muscles to shorten or contract. This is known as the sliding filament theory. Muscle contraction can be either dynamic or static (Figure 11.1).

Dynamic muscular effort consists of rhythmic contraction and extension, tension and relaxation. Static muscular work occurs where the muscle contracts for a lengthened period, usually in a postural position. As physical work patterns have changed over the years, automation, mechanisation and sedentary work has increased. This has led to decreased physical activity, constrained work postures and repetitive work movements with high speed. Static work reduces blood supply to the muscles and decreases oxygen supply, and lactic acid caused by muscular work may accumulate in the muscles. Physical factors such as cold or noise and mental demands can also increase the static muscle load. Static muscular work can cause:

- arthritis of the joints  
- inflammation of the tendons and covering sheaths  
- muscle spasms  
- degeneration of the joints and intervertebral discs of the spine.

Health effects associated with muscular work

Muscular or soft-tissue injuries can affect various parts of the body. The most likely areas of damage are the upper limbs and neck or the lower back.

Upper limb disorders are referred to as repetitive strain injury (RSI), work-related
upper limb disorder (WRULD) or cumulative trauma disorder (CTD). In Australia, the use of the term RSI has reduced, since the so-called epidemic of RSI in the late 1980s. For this chapter, CTD is the preferred generalisation for the following conditions:

- **carpal tunnel syndrome (CTS)**
- **tendonitis/tenosynovitis**
- **adverse mechanical tension.**

The main body areas that are affected are the neck, shoulder, hand, wrist, lower arm and upper arm. The disorders tend to progress through a number of stages including pain, stiffness, tingling and/or numbness. The risk factors that have been identified relating to these disorders are:

- **static posture (e.g. sitting in the same position all day, with arms flexed for typing, writing, reading or meeting people)**
- **inadequate breaks.**

If the worker maintains a poor posture, the static loading on a number of muscles increases. The muscles then become shorter and denser, impeding blood circulation, especially in the arms, neck and shoulders.

**Carpal tunnel syndrome**

CTS occurs where nerves are compressed in the wrist’s carpal tunnel, largely due to tendons expanding as a result of overuse. The nerve responds to this compression by sending back pain signals and by not carrying normal information, which provides sensation and motor impulses to the hand. High-risk industries include electronic-parts assemblers, musicians, dental hygienists, typists and meat packers.
Tendonitis and tenosynovitis

This occurs where the tendons or the tendon sheaths become abraded due to overuse. The tendon then becomes inflamed.

Adverse mechanical tension

This occurs where nerves get shortened through static posture and stress.

Back injuries

Without doubt, back injuries are one of the most significant causes of lost time from Australian workplaces. The NOHSC (1996) estimated the total annual cost of body stressing cases in 1993–94 was $9.5 billion. This was distributed as follows:

- around $4.3 billion for employers
- $2.6 billion for injured workers
- $2.6 billion for the general community.

The NOHSC estimated that the more serious injuries and diseases caused by body stressing in 1993–94 accounted for 46 per cent of all time lost through work-related injury and disease. Of these, 49.5 per cent of sprains and strains of joints and adjacent muscles occurred to the back. In many manual materials handling tasks, significant forces are produced in the lower back at the L5/S1 disc (the disc between the fifth lumbar and first sacral vertebrae).

Risk factors for muscular work

Risk factors for muscular work can be found in several checklists and tables. Generally, they focus on force, repetition of movement, posture, coupling, vibration and temperature.

- Does the task involve forceful movements or exertions?
- Does the task involve lifting or handling materials?
- What characteristics of the tool or equipment affect its grip?
- What posture is adopted? (e.g. kneeling, prolonged standing, sitting, twisting, elevation, rotation, deviation from the normal line)
- Are there any mechanical stressors?
- Are there any sources of vibration or exposure to extremes of temperature?
- How often is the task repeated? What is the cycle time?
- Is there any repeated or prolonged stress to the trunk, shoulder or upper extremities?

BIOMECHANICS

Biomechanics is the study of the way the body and its levers (bones) move. Chapter 2 stated that one of the functions of bone was to act as a lever and provide movement. A lever is a rigid body that can turn around a fixed point (the fulcrum) when a force is applied (Figure 11.2).

Force

According to Newton's second law of motion, force can be summarised as the product of an object’s mass and its acceleration (Equation 11.1).

Equation 11.1

\[ F = m \cdot A \]

Where:
- \( F \) is force (newton or kg.m.s\(^{-2}\))
- \( m \) is mass (kg)
- \( A \) is acceleration (m.s\(^{-2}\))
Force is actually a vector (i.e. it has direction). A force exerted in one direction will have an equal but opposite force opposing it in another direction. For instance, if a worker was to push a box on a smooth, flat surface (Case study 11.1), a force greater and opposite to the force exerted by the box must be exerted by the worker to move it (assuming there is no friction). If there were friction between the box and the surface, this would also need to be overcome.

This is actually Newton’s third law of motion: If an object exerts a force on a second object, the second exerts an equal and opposite force on the first.

**Work and power**

So far, we have said that force is the product of mass and acceleration. It does not take account of the length of the lever. Work is done by an object by a force when the force moves the object through a distance (d). If the force is supplied at an angle (\( \theta \)), the relationship between work, force and distance can be determined using Equation 11.2.

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**Case study 11.1**

A meat packer at an abattoir unloads boxes from a conveyor from point A to point B. The box has a mass of 16 kg. Assuming there is no friction, the force required to push the box is calculated using Equation 11.1, assuming that the acceleration required to overcome the box’s inertia is 9.8 m.s\(^{-2}\).

Therefore, the force is calculated as 16 kg \( \times \) 9.8 m.s\(^{-2}\) or about 157 newton (N).
Equation 11.2

\[ W = f.d.\cos \theta \]

Where:
- \( W \) is work (Joules)
- \( f \) is force (N)
- \( d \) is distance (m)
- \( \theta \) is angle (°)

Power is defined as the rate at which work is done or the rate at which energy is transformed, and it may be calculated using Equation 11.3.

Equation 11.3

\[ P = \frac{W}{t} \]

Where:
- \( P \) is power (watts or J.s\(^{-1}\))
- \( W \) is work (Joules)
- \( t \) is time (seconds)

Therefore, the further the muscle is from the fulcrum, the more power is generated. If the muscle is close to the fulcrum, the length of the lever is reduced and the muscle acts as a speed lever. The principles of biomechanics can be used to assess the force required to perform a task or maintain a posture or position. While it is beyond the scope of this chapter to provide comprehensive discussion about calculations of biomechanics, an understanding of the theory behind its application is useful especially in assessing the risk associated with manual materials handling tasks.

**MANUAL MATERIALS HANDLING**

Manual materials handling (MMH) or simply manual handling is defined as an activity that requires an exertion to push, pull, lift, lower, carry or otherwise move, hold or restrain an object. The risk associated with MMH can be qualitatively and quantitatively analysed using a number of techniques.

Checklists, observation and consultation are methods that can be used to identify potential hazards. The assessment will then require the consideration of several factors such as:

- **individual workers’ characteristics** — skills, age, experience, clothing, pre-existing factors that may affect risk, special needs
- **task characteristics** — actions, movements, duration and frequency of movements, load characteristics (e.g. is the load animate or inanimate?), weights, forces, working postures
- **job characteristics** — workplace layout, workstation design, work organisation and scheduling
- **environmental characteristics** — temperature, lighting, floor surfaces.

The risk assessment can be conducted from an epidemiological, psychophysical, biomechanical or physiological approach.

The epidemiological approach studies the trend of injury or signs of stress on the body in a selected area or task. It can either be retrospective (in the past) or prospective, where workers are followed to identify ill health that can be related to a specific task or risk factor. Chapter 3 described the philosophy of epidemiology.

The psychophysical method gauges workers’ perceptions about the difficulty of the work and their perceived exertion. It can also ask workers to identify any pain or area of ill health. The most commonly used tools are Borg’s rating of perceived exertion (Figure 11.3), which is available in either a 10- or 15-point scale; the Nordic musculoskeletal questionnaire; and the body part discomfort scale.
The biomechanical approach considers the individual movements within a task and models the risk depending on a number of factors such as weight, distance of the movement and frequency of the movement. Some examples are:

- **rapid upper limb assessment (RULA)**
- **video recording analysis (VIRA)**
- **Michigan 2-D and 3-D computer models**
- **NIOSH equation.**

RULA uses a worksheet to score the location of the arm, wrist, neck, trunk and leg. It also considers the force and frequency of movement. The final score indicates whether the risk is acceptable or whether further investigation and controls may be required. VIRA requires the task to be video-recorded and scored. The Michigan computer models allow the input of various parameters and predict the strength required when performing the task. Other commercial models are also available and are frequently used in industrial design or mechanical engineering. It is beyond the scope of this text to discuss the merits of each of these techniques, although it is suggested that ergonomics texts are consulted for further information.

The NIOSH equation assesses two-handed symmetrical lifting tasks and is constantly being reviewed. Recent amendments can be found on the following NIOSH Internet website.

www.cdc.gov/niosh

The most recent version of the NIOSH equation considers the following factors:

- **horizontal distance of load from the centre of ankles**
- **vertical location of hands from the floor**
- **vertical distance of travel**
- **frequency of lift**
- **coupling and grip**
- **angle of asymmetry (amount of twist).**

The NIOSH biomechanical criterion is based on lumbosacral compressive forces (LSC), which should not exceed 3400 N. It is beyond the scope of this text to describe the limitations and advantages of the NIOSH equation, although Equation 11.4 shows the revised NIOSH equation. Each of the variables shown in Equation 11.4 are defined in Table 11.1 and Table 11.2.

The recommended weight limit (RWL) is used to calculate the lifting index (LI). The LI is the ratio of the weight lifted divided by the RWL. For instance, if a worker was to lift 20 kg and the RWL is 10 kg, then the LI is 2.0. The LI can be used to rank the risk.

The NIOSH equation also now provides for analysis of tasks involving multiple stages. In such circumstances, consideration is given to the various components of the manual handling task and the risk measured.
individually and holistically. An applications manual for the revised NIOSH lifting equation is available on the Internet at the Centre for Disease Control website (www.cdc.gov/niosh).

**Equation 11.4**

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

Where:
- $RWL$ is the recommended weight limit
- $LC$ is the load constant
- $HM$ is the horizontal multiplier
- $VM$ is the vertical multiplier
- $DM$ is the distance multiplier
- $AM$ is the asymmetric multiplier
- $FM$ is the frequency multiplier
- $CM$ is the coupling multiplier.

The physiological approach measures workers' functions that could be affected by the task. For instance, heart rate, body temperature, oxygen consumption and blood chemicals. Exposure to heat stress is the most common application of these techniques, although it must be emphasised that a number of factors can affect the physiological response of a worker and it may be difficult to isolate this to one factor.

**ANTHROPOMETRY**

Anthropometry is the science of measuring the size, weight and proportions of people. It is used in almost every application that we can think of — whether designing clothes, motor vehicles, door openings or workstations. The aim of anthropometry is to provide information about a range of sizes of people, which can then be used to optimise the design of items. The benefits of using anthropometry to achieve this include:

- minimising discomfort and ill fit
- improving efficiency
- minimising errors and incidents due to poor working posture
- maximising the fit between posture, fit and visibility.

There are several types of anthropometric data including static and dynamic. Static measurements might be the height of a particular

<table>
<thead>
<tr>
<th>Component</th>
<th>Metric value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>23 kg</td>
</tr>
<tr>
<td>HM</td>
<td>(25/H)</td>
</tr>
<tr>
<td>VM</td>
<td>(1 – (0.003[V–75]))</td>
</tr>
<tr>
<td>DM</td>
<td>(0.82+(4.5/D))</td>
</tr>
<tr>
<td>AS</td>
<td>(1 – (0.0032A))</td>
</tr>
<tr>
<td>FM</td>
<td>refer to Table 11.2</td>
</tr>
<tr>
<td>CM</td>
<td>refer to Table 11.2</td>
</tr>
</tbody>
</table>

Where:
- $H$ is the horizontal location of the hands from the midpoint between the ankles
- $V$ is the vertical distance between the origin and destination of lift
- $A$ is the angle between the origin and destination of lift
- $F$ is the average frequency rate (lifts/minute). Duration is defined as $\leq 1$ hour, $\leq 2$ hours, or $\leq 8$ hours.

**Table 11.1 Revised NIOSH equation parameters**
### Horizontal Multiplier

<table>
<thead>
<tr>
<th>H (cm)</th>
<th>HM</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤25</td>
<td>1.00</td>
</tr>
<tr>
<td>28</td>
<td>0.89</td>
</tr>
<tr>
<td>30</td>
<td>0.83</td>
</tr>
<tr>
<td>32</td>
<td>0.78</td>
</tr>
<tr>
<td>34</td>
<td>0.74</td>
</tr>
<tr>
<td>36</td>
<td>0.69</td>
</tr>
<tr>
<td>38</td>
<td>0.66</td>
</tr>
<tr>
<td>40</td>
<td>0.63</td>
</tr>
<tr>
<td>42</td>
<td>0.60</td>
</tr>
<tr>
<td>44</td>
<td>0.57</td>
</tr>
<tr>
<td>46</td>
<td>0.54</td>
</tr>
<tr>
<td>48</td>
<td>0.52</td>
</tr>
<tr>
<td>50</td>
<td>0.50</td>
</tr>
<tr>
<td>52</td>
<td>0.48</td>
</tr>
<tr>
<td>54</td>
<td>0.46</td>
</tr>
<tr>
<td>56</td>
<td>0.45</td>
</tr>
<tr>
<td>58</td>
<td>0.43</td>
</tr>
<tr>
<td>60</td>
<td>0.42</td>
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<tr>
<td>73</td>
<td>0.40</td>
</tr>
<tr>
<td>&gt;63</td>
<td>0.00</td>
</tr>
</tbody>
</table>

### Vertical Multiplier

<table>
<thead>
<tr>
<th>V (cm)</th>
<th>VM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.78</td>
</tr>
<tr>
<td>10</td>
<td>0.81</td>
</tr>
<tr>
<td>20</td>
<td>0.84</td>
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<tr>
<td>30</td>
<td>0.87</td>
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<tr>
<td>40</td>
<td>0.90</td>
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<tr>
<td>50</td>
<td>0.93</td>
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</tr>
<tr>
<td>90</td>
<td>0.96</td>
</tr>
<tr>
<td>100</td>
<td>0.93</td>
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<tr>
<td>110</td>
<td>0.90</td>
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<tr>
<td>120</td>
<td>0.87</td>
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<tr>
<td>130</td>
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<td>140</td>
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</tr>
<tr>
<td>150</td>
<td>0.78</td>
</tr>
<tr>
<td>160</td>
<td>0.75</td>
</tr>
<tr>
<td>170</td>
<td>0.72</td>
</tr>
<tr>
<td>175</td>
<td>0.70</td>
</tr>
<tr>
<td>≥175</td>
<td>0.00</td>
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### Distance Multiplier

<table>
<thead>
<tr>
<th>D (cm)</th>
<th>DM</th>
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</thead>
<tbody>
<tr>
<td>≤25</td>
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</tr>
<tr>
<td>&gt;40</td>
<td>0.93</td>
</tr>
<tr>
<td>&gt;55</td>
<td>0.90</td>
</tr>
<tr>
<td>&gt;70</td>
<td>0.88</td>
</tr>
<tr>
<td>&gt;85</td>
<td>0.87</td>
</tr>
<tr>
<td>&gt;100</td>
<td>0.87</td>
</tr>
<tr>
<td>&gt;115</td>
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<tr>
<td>&gt;130</td>
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</tr>
<tr>
<td>&gt;145</td>
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<tr>
<td>&gt;160</td>
<td>0.85</td>
</tr>
<tr>
<td>&gt;175</td>
<td>0.85</td>
</tr>
<tr>
<td>&gt;175</td>
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</table>

### Asymmetric Multiplier

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<thead>
<tr>
<th>A (deg)</th>
<th>AM</th>
</tr>
</thead>
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<td>0</td>
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</tr>
<tr>
<td>15</td>
<td>0.95</td>
</tr>
<tr>
<td>30</td>
<td>0.90</td>
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<tr>
<td>45</td>
<td>0.86</td>
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<tr>
<td>60</td>
<td>0.81</td>
</tr>
<tr>
<td>75</td>
<td>0.76</td>
</tr>
<tr>
<td>90</td>
<td>0.71</td>
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<tr>
<td>105</td>
<td>0.66</td>
</tr>
<tr>
<td>120</td>
<td>0.62</td>
</tr>
<tr>
<td>135</td>
<td>0.57</td>
</tr>
<tr>
<td>&gt;135</td>
<td>0.00</td>
</tr>
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</table>

### Coupling Multiplier

<table>
<thead>
<tr>
<th>V&lt;60 cm</th>
<th>V&gt;60 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>1.00</td>
</tr>
<tr>
<td>FAIR</td>
<td>0.95</td>
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</table>

### Frequency Multiplier

<table>
<thead>
<tr>
<th>F (lift min⁻¹)</th>
<th>V&lt;60 cm</th>
<th>V&gt;60 cm</th>
<th>V&lt;60 cm</th>
<th>V&gt;60 cm</th>
<th>V&lt;60 cm</th>
<th>V&gt;60 cm</th>
<th>V&lt;60 cm</th>
<th>V&gt;60 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤2</td>
<td>1.00</td>
<td>1.00</td>
<td>0.95</td>
<td>0.95</td>
<td>0.85</td>
<td>0.85</td>
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<td>&gt;0.5</td>
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<td>0.81</td>
<td>0.81</td>
<td>0.75</td>
<td>0.75</td>
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<td>&gt;1</td>
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<td>0.65</td>
<td>0.65</td>
<td>0.55</td>
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<td>&gt;2</td>
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<td>0.91</td>
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<td>0.45</td>
<td>0.35</td>
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<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>&gt;11</td>
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<td>0.41</td>
<td>0.00</td>
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<td>0.00</td>
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<td>&gt;12</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>&gt;13</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 11.2  The six parameters for the revised NIOSH equation
population or length of the torso or weight of a selected group of individuals with similar characteristics. Dynamic data includes reach, flexibility and strength. Some sources of anthropometric data include the IWA template and mannequins or the humanscale tables. Humanscale tables provide information about dimensions, but also information such as the proportion of the population that is colourblind and acceptable forces for moving loads.

**STRESS**

Stress is now recognised as one of the most significant issues that can affect our health. But what is stress? It is often described as normal ‘wear and tear’ on the body. The body is placed under stress as it adjusts to a continually changing environment. Indeed, there is a certain level of stress in part of day-to-day living. However, it is the optimal stimulation zone that is sought. Without adequate stimulation, the body is under-loaded. With too much, it is overloaded. Stress is hazardous when:

- it occurs too often
- it is too intense
- a person’s mechanisms for coping with the stress are not adequate to counteract it.

With an optimal level of stress, performance improves. It can actually be a motivator for challenge, ambition and commitment. But too little or too much stress can cause deterioration in performance and health. The agents that cause stress are aptly known as stressors. Stressors can be work related, relationships, self-perceptions or health related. The symptoms are usually categorised as physical, psychological and behavioural, and are shown in Table 11.3.

**Managing stress**

In managing stress, it must be understood that stressors affect individuals in different ways. If the stressor arises from the workplace, the management of stress involves a committed approach by parties who might be the stressors and the stressed worker. Some strategies that may be attempted are to:

- develop accountability guidelines for managers
- provide management development programs
- develop systems for identifying and monitoring levels of occupational stress.

Recent advances in both psychology and technology make it possible to accurately assess and measure levels of stress in the individual and in the workplace. It is now possible to audit and identify areas of vulnerability in individuals and in organisations and to assist those who are at risk. Psychologists or professionals specialising in stress management should be consulted for further information.

**Occupational stress and violence**

Some industries and workplaces can place workers at risk of violence. In Australia, the incidence of violent occurrences has increased in recent years.

Examples include workplaces with extended working hours such as service stations and corner stores. Nurses and doctors may also be at risk from occupational violence. Banks, building societies and other places where money is held are targets. Similarly, places where workers deal with the public, such as schools and government departments, have potential for occupational violence. Steps
should be taken to minimise the probability of an event occurring. These might include:

- appropriate design of the office or workroom to allow easy access or egress
- appropriate design of service areas that are welcoming and calming; consideration should be given to colours, music and systems for dealing with clients in a fair manner
- barriers and emergency alarms
- distress or personal alarms
- well-lit and accessible parking.

### SHIFT WORK AND WORKING HOURS

Extended working shifts have the potential to benefit both management and the workforce. While many workplaces have introduced ten- or 12-hour shifts under enterprise agreements, either party may not have seriously considered the question of occupational health and safety impacts. The short-term advantages appear to be obvious:

- reduction in night work and fewer consecutive night shifts
- larger blocks of time for relaxation and recuperation
- improved quality of leisure time
- reduction of social problems and pressure associated with seven-day shifts and permanent night shifts.

However, in the long term, time for relaxing and sleeping are reduced when rostered on, and workers with responsibilities (e.g. childcare) may have trouble.

The literature is conflicting with regard to the detriment or otherwise of performance with extended work shifts compared with traditional eight-hour shifts. Some studies indicate that workers may cope with twelve-hour workdays while others suggest that performance deteriorates. Budnick et al. (1994) report that workers’ perceived an increased difficulty working on the first night of night shift. Productivity and safety were perceived to have decreased. Conversely, Williamson et al. (1994) noted that a change to a twelve-hour shift roster produced improvements in health, particularly in psychological health, and in reduced feelings of tiredness throughout the work period. Generally, increasing the duration

<table>
<thead>
<tr>
<th>Physical</th>
<th>Psychological</th>
<th>Behavioural</th>
</tr>
</thead>
<tbody>
<tr>
<td>grinding jaw</td>
<td>low confidence</td>
<td>insomnia</td>
</tr>
<tr>
<td>tension headaches</td>
<td>self blame</td>
<td>social withdrawal</td>
</tr>
<tr>
<td>neck and shoulder pain</td>
<td>depression</td>
<td>loss of libido</td>
</tr>
<tr>
<td>shallow breathing</td>
<td>tension</td>
<td>poor eating habits</td>
</tr>
<tr>
<td>diarrhoea</td>
<td>worry</td>
<td>rushing things</td>
</tr>
<tr>
<td>constipation</td>
<td>anxiety</td>
<td>poor time management</td>
</tr>
<tr>
<td>muscle tension</td>
<td>memory lapses</td>
<td>aggression</td>
</tr>
<tr>
<td>ulcers</td>
<td>feeling guilty</td>
<td>passivity</td>
</tr>
<tr>
<td>chest pain</td>
<td>anger</td>
<td>drinking too much alcohol</td>
</tr>
<tr>
<td>high blood pressure</td>
<td></td>
<td>poor concentration</td>
</tr>
<tr>
<td>itches or rashes</td>
<td></td>
<td>moodiness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>impatience</td>
</tr>
</tbody>
</table>
of work exacerbates the hazards. Late shift workers usually have less quality and quantity of sleep.

An increase in work duration and reduction in recovery time may induce chronic fatigue, which manifests as symptoms of tiredness (even after a period of sleep), psychological problems (mental irritability, moods of depression), a disinclination to work and general loss of vitality. This state of chronic fatigue is accompanied by disrupted sleep patterns, digestive troubles, including stomach ulcers, disturbance of eating patterns and loss of appetite. Some medical doctors and ergonomists consider the change of work practices to three or four days with increased daily work hours to be damaging to health, and reject this style of roster on medical and physiological grounds. They believe that even an increase to nine or ten working hours per day may lead to excessive fatigue and increased absenteeism through sickness. Job design and environmental factors such as lighting and air quality impact on the effects of fatigue and need also to be considered.

Twelve-hour shifts hold definite advantages for some workers’ social life, offering more consecutive days of leisure time than most other schedules. The drawback is that little free time is available on the workdays, disrupting family life and restricting social contacts and opportunities to participate in group activities. The major criteria that affect a worker’s adjustment to twelve-hour shifts include:

- **age** — older workers may experience difficulty adjusting to twelve-hour shifts, particularly if they had been on a different roster system
- **marital status** — single people may find meal organisation and social contact are affected, while married persons may experience difficulty with their relationship due to lack of contact time during shifts
- **parental status** — availability of childcare and quality of time spent with children
- **personal hobbies and interests** — rostering may interfere with team sports or organisation of activities
- **education and training**
- **shift work experience** — those on a permanent night shift may experience difficulty altering their lifestyle to a new shift system.

The risk associated with exposure to agents such as noise, vibration, chemicals and extreme temperatures differ with extended shifts since occupational exposure standards have been developed from the concept of a ‘normal’ working week (a five-day working week of eight hours’ duration per day). This implies a balance exists between accumulation of contaminant while at work and its elimination when not at work. Chapter 1 provided a technique for reducing exposure concentration due to an increase in working time.

**LIGHTING**

The term light refers to a band of electromagnetic radiation (EMR) between 380 and 780 nm that can be seen by the human eye. Light actually consists of a number of spectra or wave bands. The white light that is mostly seen consists of all of these spectra.

When light strikes the surface of an object, it can react in three ways. It can be absorbed, reflected or transmitted. Most surfaces exhibit selective reflection, which means that a certain component of the light will be reflected. This reflected light determines the colour that is perceived by the eye.

In the workplace, lighting is measured as one of four quantities (Table 11.4). For visual comfort and good optical performance in the workplace, the following conditions should be met:
• suitable illuminance levels
• balanced arrangements of the lights
• matched phasing of lights
• avoidance of glare.

**The eye’s response to light**

The organ that receives light in the human body is the eye. As light energy passes through the pupil (Figure 11.4), it is focused on the back of the eye at the retina. This stimulus is then converted to bioelectric energy and passes along the optic nerve to the eye. The retina has two types of nerve endings: cones and rods. Cones are sensitive to the quantity and quality (colour) of light but are only effective where there is adequate lighting. Rods are more sensitive to small quantities of light but are unable to detect colour.

Therefore, in dark conditions the rods predominate. But, whenever a bright light reflected from an object falls on the retina, the sensitivity is decreased. The glare or disturbance that results in the entire retina responding to a bright patch of light is known as relative glare. Therefore, it is important that lighting levels are similar in the field of vision and that general lighting levels do not fluctuate rapidly.

**Measuring light**

Light is measured using a luxmeter (also known as a lightmeter or photometer). An example is shown in Figure 11.5. The assessment is conducted according to AS1680.1. Two types of lighting surveys can be conducted:

• **average illuminance**
• **distribution of lighting and the luminance pattern.**

Lighting surveys should be conducted to check the calculated value of a new lighting system, to assess compliance or design specifications with the recommendations of the AS1680 series or to indicate whether maintenance, modification or replacement is required. The survey should begin by conducting a detailed description of the work area, including:

• lamp type and age
• luminaire and ballast type
• voltage
• interior surface reflectance
• state of maintenance
• measuring instrument used in the survey.

The luxmeter should be cosine corrected, to take account of the effect of light falling on it

<table>
<thead>
<tr>
<th><strong>Table 11.4  Photometric quantities</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantity</strong></td>
</tr>
<tr>
<td>Luminous intensity</td>
</tr>
<tr>
<td>Luminous flux</td>
</tr>
<tr>
<td>Illuminance</td>
</tr>
<tr>
<td>Luminance</td>
</tr>
</tbody>
</table>
at oblique angles, and colour corrected. Before taking the reading the photocell should be exposed to the approximate illuminance to be measured until the readings become stabilised. Measurements of illuminance should be made either after dark or with daylight excluded from the interior.

Prior to the measurements being taken, the lighting system should be operated for sufficient time to allow the light output of the lamps to stabilise. Airconditioning or ventilation systems should be operating normally.

When measuring the average illumination at a workstation, measurements should be made of the working plane (whether this is horizontal, vertical or inclined) with the worker in the normal position, even if this results in a shadow on the photocell. Most lighting surveys will involve measuring the average illuminance of an interior. The interior should be divided into a number of equal areas (as near to square as possible). The illuminance will then be measured at the centre of each, at the height of the working plane. The mean (average) of the measured illuminance values provides an estimate of the average illuminance, the accuracy of which depends on the number of measurement points and the uniformity.

The number of measurement points is determined by calculating the room index factor (K). If an accuracy of ± 10 per cent is sufficient, the number of measurement points should be no less than that specified in Appendix B of AS1680.1. For instance, if K is below one, a minimum of four measurement points should be taken.

This data is valid for luminaire spacing and mounting height ratios up to 1.5:1 provided the spacing of the grid measurement points does not coincide with the luminaire spacing. The number of measurement points recommended in the table is a minima. It may be necessary to increase this number to obtain a symmetrical grid to suit a particular room shape. If an accuracy of ± 5 per cent is required, the number of measurement points is doubled.
The room index factor is calculated using Equation 11.5. Figure 11.6 illustrates the horizontal plane containing the photometric centres of the luminaires (known as the luminaire plane).

**Equation 11.5**

\[ K = \frac{a \times b}{h(a + b)} \]

Where:
- \( K \) is the room index factor
- \( h \) is the vertical distance between the horizontal reference plane and the luminaire plane (m)
- \( a \) and \( b \) are the dimensions of the room (m)

The room index is twice the plan area of the room divided by the area of its walls between the horizontal reference plane and the luminaire plane. If the plan of the room is L-shaped (re-entrant), it should be divided into two or more re-entrant parts that can be treated separately. The results from the survey should be averaged and compared with the maintenance illuminance levels recommended in the AS/NZS1680 series.

Where an assessment of the uniformity of illuminance in an interior is required, a greater number of illuminance measurements will be needed. This determination is made using a grid of 1-m squares throughout the interior.

**Glare**

Glare occurs as a consequence of three different effects: contrast, adaptation and saturation. Glare may impair vision (known as disability glare) or it can result in discomfort (discomfort glare). Disability and discomfort glare may exist simultaneously or separately.
Saturation effects occur where the source of light is so bright that the eye cannot adapt to it. Adaptation effects occur when moving from a darkened environment to a well-lit environment. Contrast effects are caused by excessive brightness contrasts within the field of vision. The eye adjusts itself to the average luminance of the field of vision and this may result in low luminous areas being invisible and excessively lit areas causing discomfort.

**Lighting designs**

In general, lighting in the workplace should be evenly distributed and of adequate brightness. Glare should also be minimised. This can be achieved by ensuring:

- all objects and major surfaces in the visual field are equally bright
- no source of light appears in the visual field during working operations
- lights are provided with shades or glare shields to prevent the luminance of the light source from exceeding 200 cd.m$^{-2}$
- the line from the eye to the light source makes an angle of more than 30 degrees with the horizontal
- fluorescent tubes are aligned at right angles to the line of sight
- the use of reflective colours and materials on machines, tools, tabletops etc. are avoided.
SUMMARY

Ergonomics considers the relationship between the worker and work. It aims to obtain an optimal fit between the two. Ergonomics deals with physical stressors and with cognitive or psychological factors that can contribute to risk in the workplace.

This chapter has focused on industrial ergonomics and has discussed issues such as biomechanics, manual materials handling, stress, lighting and shift work.

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Chapter 12

Risk analysis

Risk analysis is a core aspect of risk management. Indeed, Australian occupational health and safety legislation has certainly increased its focus on the need to characterise, assess, communicate and manage risk. Risk is more than just a number or value about the probability of an event occurring. It also includes our perceptions, whether the risk is acceptable or tolerable and why.

This chapter aims to reinforce the meanings of hazard, risk, danger and safety. It also introduces the types of risk that workers and the community may be exposed to and offers strategies for their assessment. The debatable topic of risk perception is discussed to provide an overview of other factors that affect our response to risks. Chapter 14 expands the concept of risk management.

RISK AND HAZARD

The terms risk and hazard are often interchanged. However, their meanings are quite separate. Chapter 1 defined a hazard as the potential that an event sequence will cause damage or harm. Risk was the likelihood that an event sequence will cause damage or harm. It is the combination of frequency, duration and severity of exposure. An alternative perspective is that risk is concerned with the future and what might cause an event to occur. It also addresses change — changes in exposure or the body’s ability to deal with an agent. Risk also places an emphasis on the choices available to minimise an effect. With risk assessment, we need to ask what methods or controls are available or perhaps how many people are exposed to an event.

For an event, action or object to be considered a risk, there must be an associated loss, uncertainty or chance involved, and a choice involved that would mitigate the loss. Therefore, a high-risk event might not result in a large magnitude of loss but the outcome may be uncertain. It is also important to realise that risk does not just consider human loss. Many businesses analyse risk associated with their business operations to determine whether a decision is economically feasible and will result in positive outcomes.

A hazard, on the other hand, is fixed and not dynamic. A hazard might be a toxic substance, spillage of liquid on the floor or a biological pathogen in a Petri dish. The magnitude of hazard is determined by two factors: its characteristics (e.g. ionising radiation from a $\alpha$-source has a higher energy than non-ionising radiation such as microwaves) and its amount (whether there is a lot or a little of the hazard). In other words, hazards are a potential problem.

When measuring or perceiving risk, it is not simply a black or white decision. Imagine an office worker photocopying in a room with limited ventilation. What are the hazards? The
most significant occupational hygiene hazard is the ozone (O₃) caused from the ionisation of oxygen. Ozone is a respiratory irritant and sensitiser. The worker may be concerned about their exposure and ask whether they are at risk. The answer would be ‘yes’ — everyone is exposed to risk in some form, each day. But the important question is ‘what is the magnitude of risk?’ Is it tolerable or acceptable? The answer to these questions will depend on the dose, ventilation in the room and the person’s response to ozone.

The risk range is a term used to specify estimated risk, from the lowest to the highest. Sometimes the range (despite its simplicity) may be a most valuable risk measure. Let’s consider occupational exposure standards. These are developed by considering the effect to most workers, according to current knowledge. Therefore, it is accepted that some workers may lie outside the ‘capture area’ of no health effects. Perhaps knowledge about the hazard will change in the future when new research or information comes to light.

DANGER AND SAFETY

Does a low risk imply that a process, workplace or substance is safe? The terms danger and safety consider the human aspect of exposure to a hazard. Danger can be thought of as things that might cause peril. Another definition is that danger is liability or exposure to harm, where harm means ‘to hurt’. Some examples of occupational hygiene dangers might be:

- entering a confined space with a potential oxygen deficit or toxic or flammable gases
- handling a jackhammer that emits vibration and transfers it through the fingers and hands
- cleaning up a spillage of mercury from a blown manometer.

Safety means to be free from danger or risks. With risk analysis, we cannot guarantee that workers will be absolutely safe, although an attempt is made to achieve this level. Given the inability to finely divide events as risk-free or dangerous, it follows that safety is really a conditional goal.

DEFINITION OF RISK ANALYSIS

There are several terms that lie within the category of risk analysis. Risk analysis is broadly defined to include risk:

- assessment
- characterisation
- communication
- management and policy relating to risk.

Risk analysis applies to both the occupational setting and individuals, the public and society generally. When related to occupational hygiene, risk analysis is composed of the following distinct activities:

- hazard identification
- risk projection
- risk assessment
- risk management.

Hazard identification

Hazard identification techniques are outlined in Chapter 3. When identifying hazards and potential risks, we are attempting to find both the probability of loss and the probability of not receiving what is expected.

Risk projection

Risk projection or estimation attempts to rate the risk according to the likelihood that the risk actually exists and the consequences
of the problems associated with the risk should it occur. In essence, risk projection is the first component of risk assessment and involves:

- establishing a scale that reflects the perceived likelihood of a risk (the scale may be qualitative or quantitative)
- delineating the consequences of a risk
- establishing the impact of the risk
- appreciating the overall accuracy of the risk projection.

**Risk assessment**

Risks are weighted by perceived impact and then prioritised. Risk assessment techniques for occupational hygiene are discussed later in this chapter. The three factors that affect perceived impact are the:

- nature of the risk (which in turn indicates whether the problems are likely to occur)
- scope of risk, combining its severity with its overall distribution
- timing of a risk (when and for how long the impact will be felt).

Risk management and control emphasise a holistic approach to deal with an issue in its entirety. This aspect attempts to find solutions by considering whether the risk can be shifted or transferred and the cost/benefit of risk control. Risk strategies might include risk avoidance or limitation and risk transfer.

**Risk assessment techniques**

While we can appreciate that risk assessment is a subjective science, it is still possible to measure the level or range of risk. Risk assessment uses the best and most reasonably obtainable information from the natural, physical and social sciences. This can be performed qualitatively (judgements made that are relative to each other) or quantitatively (a specific, measurable amount). Qualitative characteristics of risk include:

- the types of health effects from exposure
- the estimated frequency of exposure (e.g. daily, weekly, monthly)
- location of a hazard in relation to the workplace or other sensitive populations.

Quantitative attributes of risk might be:

- measured exposure data
- quantity of a substance
- incidence of mortality or morbidity
- consequence analysis modelling of exposure to an agent
- modelling of frequency of exposure.

Both qualitative and quantitative components of risk should be broad enough to clearly describe the entire event. We must also explicitly state any judgements that are made in the risk assessment — such as assumptions and uncertainties. The rationale for these judgements and their influence on the risk assessments should also be articulated.

**Quantitative risk assessments**

Quantification of occupational hygiene risks will depend upon their nature, ability to be measured and appropriate benchmarks or standards. Remembering that the three components to risk are frequency, probability and outcome, these can be mathematically expressed to provide a quantitative estimate of risk.

Beginning with frequency (which is simply a rate), this should be determined using data such as historical exposure information or incident records or through modelling.
Modelling is a technique that attempts to show a pattern using known input parameters. Probability is the chance that an event will occur. It can be rated on a scale of 0 to 1, where 0 represents no chance and 1 is an absolute certainty that the event will occur.

When determining the outcome or consequence of exposure to the hazard, the following data can be measured:

- **the number of lives lost or injuries caused**
- **the cost of damage**
- **the incidence of serious ill health cases**.

A limitation of quantitative risk assessment is that, by its very nature, it does not consider our perceptions or attitudes to the hazards. As a ranking tool, quantitative risk assessment is invaluable; however, its sole use as a measure of overall risk is not recommended.

Generally, quantification of occupational hygiene hazards is left to epidemiologists and statisticians. Toxicological data is a typical example of quantitative risk assessment. In Chapter 1, terms such as the LD50 and LC50 were identified. These are calculated by measuring the duration of exposure, concentration or dose of contaminant and outcome (death). The outcomes of fire and explosion can be modelled using quantitative risk assessments. Chemical or process engineers usually conduct this. It is beyond the scope of this chapter to provide an in-depth explanation of these quantitative risk assessment techniques, although chemical engineering texts contain further detail.

**Qualitative risk assessments**

As the name suggests, risk assessments carried out using qualitative methods are subjective and open to multiple interpretations and many debates. What one person perceives to be high risk, another may accept as holding minimal risk.

In deciding upon a qualitative risk assessment technique or tool to use, it is important to consider the degree of knowledge of the workforce and the technique’s simplicity and accuracy of application. There are various methods of risk assessment used in Australian workplaces. This section outlines four tools that see use and are presented as options. However, the selection of a qualitative risk assessment tool should be at the discretion of the organisation, which should review its suitability and acceptance.

**AS/NZS4360 risk score calculator**

Australia/New Zealand Standard AS/NZS4360 Risk Management was released in 1999 and has broad application in general business risks, including occupational health and safety. The magnitude of risk is determined using a 2-D matrix and considers the likelihood and

---

**Table 12.1 Risk score calculator (from AS/NZS4360)**

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>Almost Certain</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td><strong>B</strong></td>
<td>Likely</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Possible</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>Unlikely</td>
</tr>
<tr>
<td><strong>E</strong></td>
<td>Rare</td>
</tr>
</tbody>
</table>
consequence of a hazard event occurring. Likelihood is evaluated via a 5-scale rank, from rare to almost certain. Consequence is evaluated via a 5-scale rank, from minor/personal injury to death and/or multiple injuries (catastrophic). A risk assessment rating is then given (extreme, high, moderate or low) and controls implemented according to this rating. Table 12.1 shows this matrix.

**Fine’s nomogram**

Fine (1971) has developed a risk score that incorporates the potential consequences of the incident, exposure factors and probability factor. The formula (Figure 12.1) is the product of these factors. Each of the three parameters (consequence, exposure and probability) are given a rating according to Table 12.2.

The calculated risk score can then be used to prioritise the hazard event against other hazard events, to allocate resources and control the risks. Once the risk score has been calculated, a cost justification calculation can be conducted by considering the degree of correction and cost of the intervention.

The user makes a decision about the most likely outcome if a particular hazard event were to occur, how often exposure occurs and the chance that the event will occur. It is important that the hazard event is clearly defined before the risk assessment is performed, otherwise it becomes easy to lose one’s way and predict disastrous consequences or chances that the event will occur! Unfortunately, Fine’s nomogram has the following limitations:

- **the value of input data is not necessarily based on solid grounds (an educated ‘guess’ or estimation is used)**
- **personal bias and experience will affect the final result**
- **the nomogram should be used as a baseline level of risk and not as a fine dividing line between safe and unsafe.**

A handy component of Fine’s nomogram is the justification rating that can be obtained from the risk score and projected costs of mitigating the risk. It suggests that a high-risk event that could be controlled using low-cost solutions could be easily justified. As the risk diminishes and costs increase, it becomes more difficult to justify the intervention. This philosophy has been summarised in Table 12.2.

**TTC hazard rating system**

The TTC hazard rating system uses letters of the alphabet to rank potential loss-producing incidents. A letter is given for the level of severity, level of probability and cost of corrective action (Table 12.3). These codes are then converted to a numerical rating (Table 12.4).

\[
R = C \times E \times P
\]

Where:
- \( R \) is the risk score
- \( C \) is the consequence
- \( E \) is the exposure factor
- \( P \) is the probability factor

![Figure 12.1 Fine’s risk score](image)

Source: Fine 1971, p. 158
Therefore, this style of risk assessment is useful to compare various hazard events to one another, especially when deciding on controls; however, caution should be exercised about the financial values, as they may date over time.

**FLAME model**

The FLAME model is a mission-oriented risk assessment that was developed from Fine’s nomogram and the TTC hazard rating system. It calculates a risk value by combining the following variables:

- **Frequency of process**
- **Likelihood of the hazardous event**
- **Anticipated loss**
- **Mission effects**
- **Exposed people or systems.**

The risk value (R) is calculated using Equation 12.1.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Classification</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consequence</td>
<td>Catastrophe, numerous fatalities</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Multiple fatalities</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Fatality</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Extremely serious injury</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Disabling injury</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Minor cuts, bruises, bumps</td>
<td>1</td>
</tr>
<tr>
<td>Exposure</td>
<td>Hazard event occurs:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Continuously</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Frequently</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Unusually</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rarely</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Remotely</td>
<td>0.5</td>
</tr>
<tr>
<td>Probability</td>
<td>Complete accident sequence:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is the most likely and expected result</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Is quite possible, not unusual</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Would be an unusual sequence</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Remotely possible</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Has never happened after many years of exposure, but conceivably possible</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Practically impossible</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Table 12.3  TTC code for qualitative risk assessment (adapted from Weaver 1982, p. 38)

<table>
<thead>
<tr>
<th>Criteria Level</th>
<th>Code</th>
<th>Code</th>
<th>Code</th>
<th>Code</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Fatality</td>
<td>A</td>
<td>Serious/lost time injury</td>
<td>First aid injury/no time lost</td>
<td>Injury not likely/no measurable impact</td>
<td></td>
</tr>
<tr>
<td>Probability</td>
<td>B</td>
<td>At least once a month</td>
<td>At least once a month</td>
<td>Less than once each month</td>
<td></td>
</tr>
<tr>
<td>One or more times each working day</td>
<td>C</td>
<td>$1K to $10K</td>
<td>$10K to $25K</td>
<td>$25K or more, no practical solution</td>
<td></td>
</tr>
<tr>
<td>Cost of corrective action</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than $1K or no cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 12.4  Rating the TTC hazard rating system (adapted from Weaver 1982, p. 39)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AAA</td>
<td>17</td>
<td>BCA</td>
<td>33</td>
<td>ACD</td>
<td>49</td>
<td>CCC</td>
</tr>
<tr>
<td>2</td>
<td>AAB</td>
<td>18</td>
<td>CAB</td>
<td>34</td>
<td>ADC</td>
<td>50</td>
<td>CDB</td>
</tr>
<tr>
<td>3</td>
<td>ABA</td>
<td>19</td>
<td>CBA</td>
<td>35</td>
<td>BBD</td>
<td>51</td>
<td>DAD</td>
</tr>
<tr>
<td>4</td>
<td>BAA</td>
<td>20</td>
<td>DAA</td>
<td>36</td>
<td>BCC</td>
<td>52</td>
<td>DBC</td>
</tr>
<tr>
<td>5</td>
<td>AAC</td>
<td>21</td>
<td>ABD</td>
<td>37</td>
<td>BDB</td>
<td>53</td>
<td>DBC</td>
</tr>
<tr>
<td>6</td>
<td>ABB</td>
<td>22</td>
<td>ACC</td>
<td>38</td>
<td>CAD</td>
<td>54</td>
<td>DDA</td>
</tr>
<tr>
<td>7</td>
<td>ACA</td>
<td>23</td>
<td>ADB</td>
<td>39</td>
<td>CBC</td>
<td>55</td>
<td>BDD</td>
</tr>
<tr>
<td>8</td>
<td>BAB</td>
<td>24</td>
<td>BAD</td>
<td>40</td>
<td>CCB</td>
<td>56</td>
<td>CCD</td>
</tr>
<tr>
<td>9</td>
<td>BBA</td>
<td>25</td>
<td>BBC</td>
<td>41</td>
<td>CDA</td>
<td>57</td>
<td>CDC</td>
</tr>
<tr>
<td>10</td>
<td>CAA</td>
<td>26</td>
<td>BCB</td>
<td>42</td>
<td>DAC</td>
<td>58</td>
<td>DBD</td>
</tr>
<tr>
<td>11</td>
<td>ABC</td>
<td>27</td>
<td>BDA</td>
<td>43</td>
<td>DBB</td>
<td>59</td>
<td>DCC</td>
</tr>
<tr>
<td>12</td>
<td>ACB</td>
<td>28</td>
<td>CAC</td>
<td>44</td>
<td>DCA</td>
<td>60</td>
<td>DDB</td>
</tr>
<tr>
<td>13</td>
<td>ADA</td>
<td>29</td>
<td>CBB</td>
<td>45</td>
<td>AD</td>
<td>61</td>
<td>CDD</td>
</tr>
<tr>
<td>14</td>
<td>BAC</td>
<td>30</td>
<td>CCA</td>
<td>46</td>
<td>BCD</td>
<td>62</td>
<td>DCD</td>
</tr>
<tr>
<td>15</td>
<td>BBB</td>
<td>31</td>
<td>DAB</td>
<td>47</td>
<td>BDC</td>
<td>63</td>
<td>DDC</td>
</tr>
<tr>
<td>16</td>
<td>BCA</td>
<td>32</td>
<td>DBA</td>
<td>48</td>
<td>CBD</td>
<td>64</td>
<td>DDD</td>
</tr>
</tbody>
</table>

Equation 12.1

\[ R = \log X \]

Where:
- \( X = F \times L \times A \times M \times E \)
- \( F \) is frequency of hazard-containing process
- \( L \) is likelihood of the hazardous event
- \( A \) is anticipated losses
- \( M \) is mission effects
- \( E \) is exposed people or systems

In this equation, \( X \) is determined from the product of \( F, L, A, M \) and \( E \). The frequency is
assigned a value between 1 and 100, based on whether the process has been known to occur (1) or if it occurs constantly (100).

Likelihood is based on an estimated probability and is then converted to a scoring value. So, if it is inconceivable that the event will occur, it is scored 1. If the event occurs often as part of a process and is expected, then it scores 100.

Anticipated losses are scored similarly. If there would be no apparent disruption to the process, a score of 1 is nominated. An event that results in wide-scale destruction to equipment, systems or facilities and causes many fatalities would have a value of 100.

Mission effects relate to the overall objective of the system and whether it would be affected by the event. It is scored with values ranging between 1 and 100.

The final component, exposed people or systems, allows the number of people or systems exposed to be correlated with a value. The calculated risk value is compared with a risk classification (Table 12.5).

**CONDUCTING A RISK ASSESSMENT**

In order to conduct a risk assessment with a meaningful and acceptable score, it is important to define the scope of the hazard event and its benchmark or standard. This benchmark is also known as the risk referent level, and is stated as a probability of failure or the probability of success level for each individual risk or the system as a whole. It can be:

- an aggregate of individual risks
- one or more prioritised high-impact risks.

The next step is to try to develop a relationship between each of the three parameters of risk and their referent levels. Sets of referent points that define a region of termination are then predicted. Comparing the evaluated risk with its risk referent has three possible outcomes — that the risk is:

- **acceptable** (if the evaluated risk is less than the referent)
- **impossible** (where the evaluated risk is much greater than the referent)
- **infeasible** (if the evaluated risk is greater than, but almost equal to, the referent).

**Table 12.5  Risk scores for the FLAME model (adapted from Strohm & Opheim 1993, p. 47)**

<table>
<thead>
<tr>
<th>Risk value</th>
<th>Risk classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥8.00</td>
<td>Very high risk</td>
</tr>
<tr>
<td>6.00–7.99</td>
<td>High risk</td>
</tr>
<tr>
<td>4.00–5.99</td>
<td>Substantial risk</td>
</tr>
<tr>
<td>2.00–3.99</td>
<td>Possible risk</td>
</tr>
<tr>
<td>&lt;2.00</td>
<td>Doubtful risk</td>
</tr>
</tbody>
</table>

**RISK PERCEPTION**

Why is it that what one person perceives as acceptable risk, another cannot tolerate? Risk perception is the term used to describe our insight or opinions about the acceptability of risk. The very nature of risk is subjective. Beliefs and values impact on community, government and industry’s perception of risk. It is therefore important that the application of quantitative risk assessment also addresses the uncertainty associated with such a subjective science.

While there are many methods that can be used to assess the risk associated with occupational hygiene hazards, their overall effectiveness can be questioned. Ultimately, the aim of the risk assessment tool should
be to ensure decisions relating to occupational health and hygiene hazards are made on a sound basis, will be acceptable both scientifically and socially, and are aimed at minimising the outcome or effect on the physical environment or the community.

One of the reasons for risk being such an uncertain science is a growing distrust of institutions and ‘experts’. This has led to an instinctive questioning of all government or business recommendations. Such distrust is deepened by governmental and private sector examples of incompetence in assessing risks or criminality in communications about risks associated with the development and use of some technologies. So what determines a person’s acceptance or tolerance of risk? Some parameters include:

- voluntary vs. involuntary exposure
- immediate vs. future health effects
- old (familiar) vs. new (unfamiliar) risk
- natural vs. artificial risks
- injure vs. kill hazards (magnitude of consequences)
- individual vs. external control
- monetary or other benefits vs. no benefits
- ‘fairness’ of risk distribution vs. risks concentrated among particular groups or locations
- self-appraisal of risk vs. external decision about risk
- familiarity with those producing risk vs. unknown risk producer
- complex expression of risk vs. simple language expression of risk

The first parameter illustrates where risk may be more likely to be tolerated. If an individual has control, it is more likely to be accepted. For instance, an individual may refuse to work in noisy conditions at a workplace but is exposed to high sound pressure levels when playing in a rock band on weekends. Long latency periods also affect whether we accept risk. So if the health effect is chronic (rather than acute), the exposure may be perceived to be tolerable. How often have we heard the adage that ‘if a hazard or agent has been around for years, then it can’t hurt anyone’? A mentality of ‘she’ll be right’ abounds in this area. Yet, if new technology introduces a hazard, people are concerned. Similarly, the severity of outcome will affect the acceptability of risk. If it kills, it is definitely perceived to be a higher risk.

Why is there this disparity of risk perception? The major reason is influence from the media. Most people rely on the media to provide information. Unfortunately, the media also sensationalises issues for the interest of their audience, often to the detriment of objective data. People react more to outrage than hazard; however, in fairness to the media, they are only the proponents of outrage, not the creators. The outraged public pays little attention to hazard data.

The other main problem lies in the way that risks are measured. Very often, a person’s perception of risk does not match the actual risk. This may be due to their misunderstanding of risk data or the unavailability of reliable data.

**BIAS AND RISK PERCEPTION**

Bias refers to our prejudice or inclinations. Personal biases can have a significant impact on our assessment of risk. Each of the following biases affects people’s perceptions of the probabilities of risk.

Availability bias refers to the recall between a risk and similar events that occurred. For instance, an outbreak of legionnaire’s disease
in a shopping centre may lead to an increased perception of probability of the event occurring again, compared with if a similar event had not occurred.

Representativeness bias describes whether the sample is judged to be similar to the main population.

Anchoring bias relates to where the information was obtained and whether it relates to the population. In some cases, estimates of probability are derived from some outside source and then adjusted upwards or downwards in light of new information.

Vernacular bias refers to how the results are framed. If the risk assessment presents the findings with a positive perspective, perception of risk is definitely affected. For instance, if 30 per cent of a workforce contracted a form of cancer related to work, the findings that 70 per cent of workers did not contract the disease are more positive and acceptable.

**RISK COMMUNICATION**

Effective communication of hazards and their risks is an issue that can be somewhat difficult to manage. The influence of perceptions can severely affect even the most rational worker’s ability to comprehend and accept arguments about agents. The media, especially, tend to sensationalise ‘hot’ occupational health and hygiene issues. This not only raises the issue’s profile but the ire of workers who may be affected. The issue of asbestos always tends to cause workers’ blood to boil, even if the full extent of exposure is not known. Similarly, issues such as exposure to radio frequencies around overhead power lines and telecommunications causes dissension in the community.

Risk communication can be approached in a number of ways. The decision about appropriate strategies will depend on the nature of workforce, the hazard that is being discussed and the likely feedback from the workforce. In some cases, it may be appropriate to attempt several forms of risk communication before an optimal approach is found. The four methods of risk communication are:

- none — ignore others
- one way — show others they are wrong
- two way — exchange information and learn
- internalised — each becomes an integral part of the process.

The principles for effective risk communication in the workplace are:

- risk communication should involve the open, two-way exchange of information between professionals and workers
- questions and honest, open dialogue should be encouraged; it is best to honestly answer such questions in a way that is easily understood
- an organisation should make its risk management goals clear to workers; the aims of risk assessments and risk management decisions should be communicated accurately and objectively in a meaningful manner
- data, models and inferences used or relied upon in the risk assessment or decision should be described, in order to maximise worker understanding and participation in risk analysis
- information sources and uncertainties should be identified
- appropriate risk comparisons should be made; this might include taking into account public attitudes with respect to voluntary versus involuntary risks
- feedback and information should be provided in a timely manner
• workers should be allowed access to relevant documents.

The first step of successful risk analysis and communication should be to involve both quantitative methods of risk assessment and an evaluation of the health risks as perceived by the population. The exclusive use of quantitative risk assessments limits the effectiveness of an agreeable outcome, as many risk assessment studies overstate exposure and risk estimates due to methodological problems. This compounds as a negativity and loss of confidence in the risk assessment process in the view of the workforce.

The second step relates to the characterisation of health and social aspects of risk. This could be conducted through the use of tools such as toxicology, modelling, epidemiology and surveillance.

The final aspect of the combined process involves reassessment, assurance and evaluation. Since the ultimate goal of the combined approach is to utilise the benefits of risk assessment to achieve better decisions regarding occupational hygiene risks, it is imperative that the interventions are reviewed. Success could be measured through the improvement of workers’ health.

SUMMARY

Risk analysis can be objective or subjective. There are several terms that lie within the category of risk analysis. Risk analysis is broadly defined to include risk assessment, characterisation, communication and management relating to risk. Risk analysis applies to both the occupational setting and individuals, the public and society generally. This chapter has identified four methods for risk analysis: the AS/NZS4360 risk score calculator, Fine's nomogram, TTC hazard rating system and FLAME model.

BIBLIOGRAPHY AND FURTHER READING

Cothern, C.R. 1996, Environmental Risk Decision Making — Values, Perceptions, & Ethics, Lewis Publishers, USA
Australia/New Zealand, North Sydney
Strohm, P.F. and Opheim, G.S. 1993, ‘Mission-Oriented Risk Assessment’, *Professional Safety*, June,
pp. 38–43
Much of the practice of occupational hygiene concentrates on hazard identification and evaluation of risk; however, if the hazard is not controlled these first two steps are futile. It is imperative that control is always an outcome of the correct recognition and assessment of agents that can harm workers’ health. The aim of occupational hygiene risk control is to design or find methods that will minimise exposure, whether the hazard is physical, chemical, ergonomic or biological.

This chapter deals with the concept of control including its aims, types and the hierarchy of control. It focuses on ventilation such as local exhaust ventilation, general dilution ventilation and the design of ventilation systems. The use of personal protective equipment as a control option is also discussed, along with guidance on how to select, use and maintain respiratory protection devices. Controls relating to noise, vibration and biological hazards are discussed in the chapters that dealt with these specific hazards.

THE AIMS OF CONTROL

There are six fundamental reasons for implementing occupational hygiene controls. The impetus may be financial, regulatory, ethical or industrially related. For instance, the occupational health and safety professional aims to minimise exposure to protect workers and comply with regulatory requirements. An accountant or risk manager, on the other hand, may consider the financial loss associated with an incident or failure to control risk. Chapter 14 expands our discussion about occupational hygiene risk management. Whatever the reason, controls need to be realistic and cost-efficient. Indeed, an indirect outcome of control may be an increase in efficiency and overall reduction of costs. The six aims of occupational hygiene risk control are:

- protection of exposed workers’ health
- ensuring workers’ comfort and safety
- compliance with legislation
- protection of other workers and people who may be affected by the risks created by a process or workplace
- reduction in environmental pollution and damage to the environment
- minimisation of economic loss from raw materials, products or valuable wastes.

In many cases, there are several options available for control. Sometimes, the optimal control may not be the most practicable and an alternative needs to be considered. Perhaps more than one control is required to reduce exposure to an acceptable level. While control
may not eliminate the hazard, it will reduce the magnitude of exposure to some extent.

**TAKING A METHODICAL APPROACH TO CONTROL**

Let’s face it, controlling hazards can be expensive — especially when the wrong option is chosen, resulting in further assessments and installations to be implemented. To prevent this expense and inconvenience, a methodical approach to control is required:

1. Identify the nature and source of hazard.
2. Characterise the exposure profile.
3. Consider the emission source(s) and nature of emission.
4. Characterise the worker(s) and workplace.
5. Identify current controls and assess their efficiency.
6. Brainstorm alternative controls that are cost-effective, efficient and acceptable to the workplace.
7. Select the most practicable control option(s) after considering regulatory requirements, costs, extent of hazard reduction and ethics.
8. Trial the anticipated controls.
9. Seek feedback and evaluate the effectiveness of controls.
10. Re-assess the implemented controls to ensure their suitability.
11. Regularly maintain controls for continued efficiency and effectiveness.

Using the principles of risk management, the hazard is firstly identified and then assessed. Recognition of the hazard is achieved by understanding the exact nature of the hazard, its physical state and source of generation or emission.

Next, the characteristics of the worker(s) and the workplace are identified and related to the exposure. Workers’ exposure can be divided into homogenous groups, depending on the type of contaminant to which they are exposed. Some questions that need to be asked include:

- Is the worker sited close to the source of the emission?
- What personal characteristics (e.g. height, predisposing health factors, ability to wear protective equipment) impact on exposure?
- What work practices are adopted?
- What is the level of education and training of workers?
- How is the workplace laid out?
- Are there areas of little ventilation?

These points would be incorporated into the risk assessment. Ideally, the assessment would be quantitative and could be compared with benchmarks, for instance, collecting exposure data that is compared with an occupational exposure standard.

Some workplaces may already have controls in place. Before other options are fully investigated, existing controls should be identified and assessed. This can be achieved by:

- surveying workers’ attitudes to hazards and current controls that are in place
- monitoring workers’ exposure to contaminants and occupational hygiene hazards
- reviewing health surveillance data and workers’ compensation records for incidents of work-related illness or injury that can be attributed to insufficient control of the hazard
- direct measurement of the performance of control systems, such as ventilation, and comparing with performance and efficiency standards.

Once the existing level of control has been established and the full extent of the problem is
understood, it is time to generate a ‘think-pot’ of ideas for control. Often, the best ideas come from those who are exposed to the hazard and are familiar with the process — the workers. Involvement of workers in the identification, design and implementation of controls is useful in several ways:

- it promotes consultation between employers, supervisors and workers
- workers feel a sense of ownership and empowerment of decisions that they have been involved with
- job satisfaction may increase in the realisation that workers’ opinions are valued and sought after
- workers have intimate knowledge of the workings of a process or system and whether the proposed controls are practical and usable.

Sometimes, this stage of the risk management process can become frustrating and tedious. Certain factions may have conflicting agendas and motives for consultation and negotiation. In such cases, it is important to remain objective about the aim of controls and not become involved in party arguments or industrial discussion which are not relevant to the issue under consideration.

After considering the merits of optimal control strategies, these must be fully costed and evaluated in terms of their anticipated suitability to control the hazard. For instance, personal protective equipment may be preferred as a short-term control for exposure to noise or hazardous substances. But the long-term costs far outweigh alternatives such as engineering controls. In some cases (e.g. emergency rescue) personal protective equipment may be the best option. Regulatory requirements may also dictate the approach that is taken to minimise risks in the workplace.

Once a decision about the controls has been made and they are implemented, the process does not end! A thorough investigation of the effectiveness of the controls should be conducted. Where deficiencies are identified, alterations to the implemented systems may be required. Or, in worst case scenarios, the organisation may need to go back to the drawing board to totally review the situation and approach again.

METHODS OF CONTROL

Ultimately, occupational hygiene risk control should begin during the design phase of a process or workplace. It is more expensive and inconvenient to attempt to redesign and retrofit a workplace once it has been built. While this idealist approach may work with new operations, most hazards exist in a workplace that has been run for many years. An alternative approach is therefore needed! Let’s consider the three factors required for exposure:

- a source (the occupational hygiene hazard)
- a mechanism or path for movement of the hazard
- an unprotected receiver.

Removal of any of these partners in the exposure triangle will minimise exposure. As an example, a solvent-based paint could be substituted for a water-based alternative. Perhaps chemical bonding of materials could be attempted instead of heating and welding. Or a different state of matter could be chosen — a pellet instead of a powder. Where the process or inputs cannot be changed, transmission of the hazard to the worker can be halted or, at the least, reduced. Emissions such as dust, gases and fumes could be collected or diluted with ventilation. A physical barrier may isolate the hazard from one area of the workplace to another. Of course, the application of such techniques will require special consideration of the behaviour of the source and whether it is amenable to control in this manner.
The last option for control is to stop the hazard at the worker. These controls are the least preferred as they rely on human behaviour and accept the hazard has not been eliminated or reduced in another way. Training, education, worker rotation and personal protective equipment are strategies that can be tried.

**HIERARCHY OF CONTROL**

The hierarchy of control is a list of control options that have been placed in a preferred order. It addresses the three mechanisms for exposure reduction with an alternative categorisation scheme:

1. Elimination
2. Substitution
3. Engineering (by ventilation or isolation)
4. Administration
5. Personal protective equipment.

**Elimination**

While elimination is accepted as the best option for controlling exposure, it also can be the most impractical. An organisation may not be able to eliminate a substance or process without compromising its entire production or the viability of the company. Historically, elimination of the hazard has involved the closure of industries. Some examples include:

- **production of matches with white phosphorous was ceased and replaced with red phosphorous** — this was due to necrosis of the jaw (‘phossy-jaw’) in unprotected workers
- **the gradual reduction of production of leaded fuel**
- **reduction in the use of lead-based paints.**

**Substitution**

Where the hazard cannot be totally removed, the second preferred option considers an alternative process or material. Substitution often involves a substantial amount of trial-and-error to determine whether the alternative substance or technique is as efficient as the previous. It is also important to stress that the substituted agent must have a known and lower toxicity than its predecessor. If a supplier is uncertain of the risk associated with a new process, it is still safer to remain with a hazard whose nature is known.

Some examples of substituted hazards include:

- **vegetable oil-based inks such as soya-bean oil instead of chemical inks in newsprinting presses**
- **metal slag instead of silica sand for abrasive blasting**
- **oil as opposed to mercury in barometers and gauges**
- **replacing carbon tetrachloride and other solvents with 1,1,1 trichloroethane** (which in turn is being phased out because of its ozone-depleting characteristics).

Processes can also be altered to minimise the probability of exposure. These include:

- **transporting toxic substances such as cyanide as solid briquettes rather than as powders, dusts or liquid**
- **wet sweeping of lead dust on the floor of a shooting gallery rather than dry sweeping or air-jet blowing**
- **substituting high-velocity processes for those of a lower velocity.**

While some of these examples are actually engineering controls, in their simplest form they are still substituting one process for another.
Case study 13.1

Asbestos is a mineral fibre that has exceptional thermal and abrasion resistant properties. Due to these characteristics, it was used as a form of insulation or lagging around high-temperature and high-pressure pipes in chemical processing industries. Since asbestos has been associated with lung conditions such as asbestosis, lung cancer and mesothelioma, its use has gradually decreased and during routine maintenance it has been replaced with synthetic mineral fibre lagging. Synthetic mineral fibres are believed to present less risk than asbestos, according to current knowledge.

Engineering controls

This broad category of controls is probably the most commonly used. Its advantages lie in the ability to physically alter the path of transmission of the hazard or isolate the worker from the agent. The three alternatives are: segregation or isolation; guarding and signage; and ventilation.

Segregation or isolation

Segregation or isolation relies on the principle of enclosing either the hazard or worker to restrict movement of the hazard. Segregation can be achieved by placing a physical barrier between one area of the workplace to another, separating by time or by distance. Examples of segregation include handling a pathogenic organism inside a Class I or II biological safety cabinet or relocating a dusty process to an isolated section of the plant.

Isolation requires physical detachment of the process or person, for instance, remotely operating a crane from a control centre, pumping cleaning chemicals in a hospital from an enclosed system or enclosing a noisy process in a sound-insulated booth.

Guarding and signage

Guarding and signage reduce the path between the hazard source and the worker. Both controls have one aim in common — to distance the worker from the hazard, either by space or time. With guarding, a physical barrier is installed to prevent access to a hazardous area. Some examples of guarding of occupational hygiene hazards include a ventilated booth for...
spray-painting that prevents drift of paint and exposure to solvents of adjacent workers or closing the lid of a photocopier when copying to minimise exposure to high-intensity light and premature wearing of the photosensitive drum.

In the workplace, signage is often used extensively to provide information or warnings (Figure 13.1). Therefore, it is actually a barrier whose information or instructions should bring compliance. For this reason, signs must be easily understood and interpreted, otherwise their use as a control is extremely limited. Since signage relies on our responses and interpretation to make a decision not to enter an area, it uses time as a control. AS1319 is the recommended standard to which occupational health and safety signs should comply.

Ventilation

For atmospheric contaminants, ventilation is the most effective control (once elimination and substitution have been negated). In fact, most buildings and workplaces depend on ventilation either for comfort, temperature regulation or contaminant control. Table 13.1 shows the most common categories of ventilation used in industrial workplaces or office environments. A detailed discussion about these types of ventilation systems and their applications is included later in this chapter.

**Administrative controls**

As we move further down the hierarchy of control it becomes apparent that administrative controls become one of the least preferred options. The main reason for this is that these controls rely on human behaviour and compliance for success. Where the risk is low, administrative controls may be considered; however, if the risk is significant, administrative controls by themselves should be viewed with caution.

Indeed, many workplaces incorporate administrative controls into a holistic approach to control. In other words, several control

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat, ventilation and airconditioning</strong> (HVAC)</td>
<td>Air is taken into a workplace and is heated or cooled, and the humidity is adjusted to a comfortable level.</td>
</tr>
<tr>
<td><strong>Local exhaust ventilation (LEV)</strong></td>
<td>Uses a hood to capture contaminants at or close to the source. The contaminant is transported via ducting to an air cleaner and emission stack.</td>
</tr>
<tr>
<td><strong>General dilution ventilation</strong></td>
<td>Air naturally diffuses into the workplace through open windows, doors and leaks in the building to sweep the contaminants out using the principles of dilution.</td>
</tr>
<tr>
<td><strong>Forced dilution ventilation</strong></td>
<td>A similar principle to general dilution ventilation, except that air is pumped into the workplace by the use of a fan or other device.</td>
</tr>
</tbody>
</table>
techniques are used to reduce exposure to a level as low as reasonably achievable. Some instances where administrative controls may be used include:

- **low-level exposure**
- **infrequent exposure**
- **minimal health or safety consequences if exposure does occur.**

In these situations administrative controls which concentrate on the worker rather than the workplace may be appropriate. Some examples of these controls are:

- **worker rotation and job placement**
- **education and training**
- **good housekeeping and hygiene**
- **maintenance**
- **scheduling of work**
- **monitoring and health surveillance.**

**Worker rotation and job placement**

This method aims to reduce an individual's overall exposure by sharing the work amongst several workers. For instance, hot work such as welding the crushing drums in a sugar mill could be performed by a team of welders. Multiskilling of workers in a dry-cleaning establishment means that the time spent exposed to perchlorethylene is minimised by swapping to an alternative task such as ironing. Job placement incorporates a number of issues such as fitness-for-work and a person's ability to perform the task. If a worker suffers a pre-existing condition or illness, they should not be placed in a job that is likely to exacerbate the condition or cause deterioration of health.

**Education and training**

Education and training assist workers in performing their work safely. With knowledge and understanding about the risk associated with a task and methods of combating exposure, workers can make an informed decision about their exposure. Some examples of information sources include:

- **material safety data sheets for hazardous substances**
- ‘**toolbox talks’ and sharing information between supervisors or management and workers**
- **technical documents or brochures about tools, equipment and plant**
- **on-the-job training such as the ‘buddy–buddy’ system, apprentice training at group training organisations and demonstrations**
- **professionals who provide training about occupational health and safety hazards.**

**Good housekeeping and hygiene**

Not only will housekeeping minimise safety-related incidents such as trips, slips and falls but it also serves to reduce the amount of dusts and other contaminants that may become airborne. Personal hygiene is also an issue in controlling accidental exposure. Substandard hygiene can lead to inadvertent ingestion of contaminants, for instance, by smoking, eating food without washing the hands first or drinking from a contaminated source.

Cross-contamination between the workplace and home can also occur where dirty work clothes are taken home for washing. A poignant reminder of the danger of this practice is the families of Wittenoom asbestos miners who contracted asbestos-related diseases from exposure to the contaminated clothing of their partners or fathers.

**Maintenance**

Scheduled maintenance of tools, equipment and plant is necessary to minimise wear and associated loss of performance. This inefficiency can be transformed into an alternative damaging
form of energy. For instance, vibrating machinery that is not solidly mounted can resonate vibrational energy through floor surfaces or walls. Maintenance procedures should also be used to check the performance of control systems such as ventilation. In some cases, it may be necessary to repair damaged or ineffective controls.

**Scheduling of work**

This method of control uses the principle of time, as described in engineering controls. High-risk work can be rescheduled so that the least numbers of workers are likely to be exposed or inconvenienced. Some examples include:

- demolition of buildings on weekends or non-peak hours to minimise dust, noise and vibration exposure to adjacent buildings
- pouring of molten metal during the afternoon shift where fewer workers will be exposed
- fumigation of buildings during holiday periods or weekends
- limiting the exposure of sensitised or susceptible populations exposure to sensitising substances.

**Monitoring and health surveillance**

Occupational hygiene and biological monitoring are methods that can be used to assess risk and track the success of controls. By themselves, they are not effective controls unless coupled with additional strategies.

Some States and Territories of Australia require health surveillance and occupational hygiene sampling to be conducted, according to the NOHSC National Model Regulations for Control of Workplace Hazardous Substances. Other organisations use this technique as a method of gauging whether their controls are actually working.

As a final note, it is important to remember that administrative controls rely on peoples’ behaviour for their success. As such, it is vital that workers are adequately and honestly informed of the aims, procedures and limitations of the controls, together with the possible adverse outcomes of noncompliance. Therefore, issues such as worker motivation, morale, involvement and participation should be addressed before attempting to implement these styles of controls.

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**Case study 13.2**

Exposure to inorganic lead chiefly occurs through inhalation of dust and fume. However, an often overlooked route of entry is through accidental ingestion. In the radiator repair industry, lead-based solder is used to repair holes in the radiators. This can generate significant amounts of lead oxide (PbO) fume. If the hands are not protected, the dust also can settle on the skin and become embedded beneath the fingernails.

Exposure to inorganic lead occurs after repairing the radiators and eating, drinking or smoking without washing and scrubbing the hands first. The lead dust is transferred to the food, tip of cigarette or drinking container where it is taken through the mouth and into the digestive system. Some absorption of lead occurs in the gut.

Exposure to inorganic lead occurs after repairing the radiators and eating, drinking or smoking without washing and scrubbing the hands first. The lead dust is transferred to the food, tip of cigarette or drinking container where it is taken through the mouth and into the digestive system. Some absorption of lead occurs in the gut.
**Personal protective equipment**

Personal protective equipment is the final barrier against occupational hygiene hazards. It includes items such as:

- respirators
- gloves
- overalls and aprons
- boots
- glasses, goggles and shields
- hearing protection devices (e.g. earmuffs, earplugs, helmets).

More detailed information about personal protective equipment is provided later in this chapter.

**VENTILATION**

Table 13.1 showed the four types of ventilation that are commonly used in workplaces. To further simplify our description, ventilation can be categorised as dilution ventilation or local exhaust ventilation (LEV) (Figure 13.2). A basic understanding of the physics of airflow and contaminant removal is required in order to select the best type of ventilation for any given scenario. Overall, LEV is most suited to situations where:

- the contaminant is generated from a single source or line source
- the contaminant can be captured before it reaches the workers’ breathing zone
- the emission rate is not constant.

As the name suggests, dilution ventilation introduces clean air into a workplace to reduce the concentration of contaminant. Both dilution and local exhaust ventilation will now be discussed in further detail.

**DILUTION VENTILATION**

Both forced and natural dilution ventilation operate with the same principle: reduction of the concentration of a contaminant by clean air. The most suitable situations where dilution ventilation (Figure 13.3) can be used are:

- for low-toxicity contaminants
- where the generation of contaminants occurs relatively uniformly in time
- if the source of emission is not a point source and is dispersed throughout the work space
- where outdoor air is less contaminated than indoor air
- where exposure concentrations are less than the occupational exposure standards or indoor air quality guidelines (where applicable)
- where general emission of the contaminant is not in the breathing zone
- where the existing HVAC system is capable of being used for the application.

Ultimately, its application is only valid where the substance is released consistently throughout the workplace at a relatively slow rate and has a low toxicity. Some examples of dilution ventilation include:

- opening windows or louvres to allow cross-ventilation through an office or workplace
- fans that force air from behind the worker and displace the contaminant away from the breathing zone
- HVAC systems that heat or cool and adjust the humidity of air in offices.

Depending upon the nature of the hazardous substance, the type of air-movement system
Figure 13.2  An example of local exhaust ventilation while welding

Figure 13.3  Dilution ventilation in a workshop, using a pedestal fan
required for the workplace will differ. Sometimes, an air-exhaust system or combined supply-exhaust system may be used. The supplied air should be introduced along one side of the work area and exhaust openings located on the opposite side of the room to ensure the airflow pattern is not 'short-circuited' and disrupted. Any air exhausted from the workplace must be replaced by an equal amount of uncontaminated fresh air to ensure hazardous concentrations of substances do not build up in the workplace due to an excessive negative pressure.

**Designing a dilution ventilation system**

If one or more of the selection criteria is met, dilution ventilation may be the best option for controlling exposure to a contaminant or maintaining a comfortable work environment. To decide on the system requirements, we must take account of:

- **the nature of the contaminant to be diluted**
- **the work environment (its volume, current ventilation system, location of inlets and outlets, number of occupants)**
- **the rate of emission of the contaminant and removal from the current ventilation system**
- **the occupational exposure standard or other benchmark that is acceptable and meets regulatory or the organisation’s requirements.**

**Nature of contaminant**

The nature of contaminant considers its toxicity, state of matter, size, shape and method of emission. Is the contaminant a gas or a dust? What health effects can be expected from exposure? Does it cause mild irritation or severe asthmatic responses?

**Work environment**

A survey of the workspace or room will easily identify the characteristics of the area that will either make it conducive, or limit the application of dilution ventilation. Some questions that should be asked are shown below:

- **How many people occupy the room at any one time?**
- **What process is conducted in the area?**
- **What are the temperature and environmental conditions in the room?**
- **Is the contaminant steadily emitted?**
- **What mixing of air is there?**
- **What equipment or tools are used in the room or space?**
- **Where and how are wastes disposed of?**
- **Are there any ‘dead spots’, draughty areas or areas with turbulent airflow?**

The volume of the room can be determined using a simple calculation of the product of the height, length and width of the room. It is measured as cubic metres (m$^3$). It is normal to subtract volumes that are not occupied such as cupboards and cabinets.

To understand the current ventilation system it may be necessary to consult the air-conditioning or maintenance engineer. Plans may be available of the existing ducts, fans, outlets and inlets. These plans may be complex or even dated. It is therefore vital that recent information about the system is obtained.

An important point about airflow was identified earlier. We need to ask whether there are any areas that are draughty or turbulent or have inadequate air movement. Technically speaking, airflow relates to the velocity of air.
The product of velocity \((v)\) and cross-sectional area of a duct \((A)\) determines the airflow rate \((Q)\) (Equation 13.1).

**Equation 13.1**

\[ Q = v \cdot A \]

Where:
- \(Q\) is airflow rate \((m^3.s^{-1})\)
- \(v\) is air velocity \((m.s^{-1})\)
- \(A\) is the area \((m^2)\)

If the duct diameter changed at some point, the mass of gas (or air) flowing through the duct will be exactly equal as it flows through the duct at a flow rate of \(Q\) \((m^3.s^{-1})\). In other words, \(Q_1 = Q_2\) where \(Q_1\) is the flow rate at one duct diameter and \(Q_2\) is the other point in the duct.

**Example 13.1**

An occupational hygienist measures the average velocity travelling out of an airconditioning duct as 8 m.s\(^{-1}\). The duct is circular and has a radius of 10 cm. What is \(Q\)?

Answer:

\[ Q = v \cdot A \]
\[ = 8 \cdot m.s^{-1} \times (\pi \cdot r^2) \cdot m^2 \]
\[ = 8 \cdot m.s^{-1} \times (\pi \cdot (0.1)^2) \cdot m^2 \]
\[ = 0.25 \ m.s \]

**Case study 13.3**

A shoe manufacturing workplace uses a solvent (toluene) to glue shoes together. It is known that 100 g of the solvent has evaporated into the work room. The room where the substance is used is not ventilated and has the dimensions of 10 m x 10 m x 3 m.

The concentration of toluene in the air is determined to be 100 000 mg/10 x 10 x 3 m\(^3\) or 333 mg.m\(^{-3}\).
Equation 13.3

\[ C = \frac{E}{Q} \]

Where:
- \( C \) is the concentration of contaminant (mg.m\(^{-3}\))
- \( E \) is the rate of release of contaminant (mg.s\(^{-1}\))
- \( Q \) is the flow rate of air into the room (m\(^3\).s\(^{-1}\))

Example 13.2

A solvent evaporates at 100 mg.s\(^{-1}\) from a tank. The room ventilation rate is 1 m.s\(^{-1}\). Assuming perfect mixing, what is the solvent concentration in air?

Answer:

\[ C = \frac{100 \text{ mg.s}^{-1}}{1 \text{ m}^3 \text{s}^{-1}} = 100 \text{ mg.m}^{-3} \]

Occupational exposure standards

When designing a dilution ventilation system, an acceptable standard of concentration must be determined. Typically in Australia, this would be the national exposure standard. However, some organisations may set a best-practice level that is below the national standard. Whatever the benchmark, the acceptable concentration must be specified before the dilution ventilation system can be properly designed. The airflow rate (\(Q\)) required to maintain the concentration of a substance below its occupational exposure standard can be calculated from:

- the emission rate of the substance (mg.s\(^{-1}\))
- the exposure standard (L).

Assuming good mixing, the airflow rate (\(Q\)) is determined from Equation 13.4.

Equation 13.4

\[ Q = \frac{E}{L} \]

Where:
- \( Q \) is the ventilation rate (m\(^3\).s\(^{-1}\))
- \( E \) is the emission rate (mg.s\(^{-1}\))
- \( L \) is the exposure limit (mg.m\(^{-3}\))

Mixing factor

Earlier, the mixing factor or ventilation effectiveness (\(K\)) was identified as a value that takes account of incomplete or poor delivery of air used in dilution ventilation. When designing the required minimum airflow rate (\(Q\)) in either Equation 13.3 or 13.4, good mixing was assumed. However, since most workplaces are not perfect, the mixing factor

<table>
<thead>
<tr>
<th>Mixing factor (K)</th>
<th>Examples of conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Open-design office spaces without partitions or restrictions. No source of contamination.</td>
</tr>
<tr>
<td>1.2–1.5</td>
<td>Inlets and outlets placed in inappropriate positions like garages or driveways. Partitioned work areas with barriers. Small point source emission of contaminant.</td>
</tr>
<tr>
<td>1.5–3.0</td>
<td>Crowded area with substandard inlet and outlet location. Many walls and barriers. Noticeable point source emission of contaminant emission.</td>
</tr>
</tbody>
</table>
must be taken into account. Table 13.2 shows some typical values of \( K \), which vary from 1.0 to 3 in most situations.

Therefore, the dilution airflow rate that is required in most situations (\( Q_{\text{eff}} \)) will take account of the airflow rate, mixing factor and the occupational exposure standard (Equation 13.5).

**Equation 13.5**

\[
Q_{\text{eff}} = \frac{E}{L} \times K
\]

Where:
- \( Q_{\text{eff}} \) is the effective ventilation rate (\( \text{m}^3.\text{s}^{-1} \))
- \( E \) is the emission rate (\( \text{mg}.\text{s}^{-1} \))
- \( K \) is the mixing factor
- \( L \) is the exposure limit (\( \text{mg}.\text{m}^{-3} \))

In general, the following principles should be adopted when designing a dilution ventilation system:

- **locate the fresh air intake away from possible contamination sources** (such as driveways with car exhaust emissions)
- **an equal volume of air removed by general ventilation systems must be supplied by make-up air**
- **make-up air should be supplied by fans and ducts**, as it is difficult to control the quality of air drawn in other ways (e.g. through doors or openings in the building)
- **make-up air should be heated or cooled to approximately the same as desired in the room being supplied.**

**Air change rates**

Air change rates are used by ventilation engineers and describe the number of times air is moved out of a room in a given time. These rates are usually expressed in air changes per hour or air changes per second. Equation 13.6 shows how to calculate air changes per second. To convert this to air changes per hour, the calculated value of \( N \) is multiplied by 3600.

**Equation 13.6**

\[
N = \frac{Q}{V}
\]

Where:
- \( N \) is the air change rate (changes.sec\(^{-1}\))
- \( Q \) is the airflow rate (\( \text{m}^3.\text{s}^{-1} \))
- \( V \) is volume of space (\( \text{m}^3 \))

In Australia, there are no legislative requirements for air change rate; however, it is generally recommended that higher rates are required in areas that generate contaminants or odour. Public places also require a higher air change rate. Table 13.3 shows some recommended air change rates for various areas.

**Purging**

The term purging relates to clearing the air by evacuation. It can be performed by either sucking or blowing air into or from a contaminated space. Blowing or pushing air
into the area allows more effective mixing than sucking. The concentration of contaminant is reduced exponentially over time. This reduction can be expressed mathematically, as shown in Equation 13.7.

**Equation 13.7**

\[ C = C_0 e^{-\frac{Qt}{V}} \]

Where:
- \( C \) is the final concentration
- \( C_0 \) is the concentration at time \( t \)
- \( Q \) is the airflow rate \( (m^3 \cdot s^{-1}) \)
- \( t \) is time \( (sec) \)
- \( V \) is volume of space \( (m^3) \)

Therefore, the time that it would take to reduce the concentration of a contaminant to a specific level can be determined by extrapolating Equation 13.7 to Equation 13.8. An example is provided in Example 13.3.

**Equation 13.8**

\[ t = \frac{V}{Q} \ln \left[ \frac{C_i}{C_f} \right] \]

Where:
- \( Q \) is the ventilation rate \( (m^3 \cdot s^{-1}) \)
- \( \ln \) is natural log
- \( C_i \) is the initial concentration
- \( C_f \) is the final concentration
- \( t \) is time \( (sec) \)
- \( V \) is volume of space \( (m^3) \)

**Example 13.3**

A confined space with a volume of 100 \( m^3 \) has a measured concentration of 1000 ppm of carbon monoxide (CO). The airflow rate is 0.5 \( m^3 \cdot s^{-1} \). How long would the space have to be purged to reduce the concentration to 30 ppm?

**Answer:**

\[ t = \frac{V}{Q} \ln \left[ \frac{C_i}{C_f} \right] \]
\[ t = 100 \ m^3 / 0.5 \ m^3 \cdot s^{-1} \cdot \ln \left[ \frac{1000}{30} \right] \]
\[ = 701 \ \text{seconds or 12 minutes} \]

**LOCAL EXHAUST VENTILATION**

Local exhaust ventilation systems are designed to collect contaminants as close to the origin or source as possible. They can be used:

- for relatively toxic contaminants
- where the generation of contaminants occurs intermittently
- if the source of emission is a point source
- where the emission source is relatively fixed
- where the worker is located close to the source of emission
- if other cost-effective options are not viable.

An LEV system has the following basic elements:

- a hood to capture the contaminant
- ducts to transport the contaminant
- air-cleaning devices to remove contaminants from the air
- fans that move the air through the system and discharge exhausted air outside
- a stack or emission point.

The hood or canopy provides a point of ingress for the contaminant. It can have an open face or flanges to help direct air movement. A correctly designed hood is integral to the efficiency of LEV. If the hood is poorly designed and cumbersome, the worker may not use the system. Similarly, if it does not encourage the contaminant into the LEV, it is useless. Ducts or piping are transport mechanisms for the contaminant to travel from the source to its eventual emission point. The construction of ducts will depend upon the contaminant (i.e. corrosive or acidic dusts will abrade steel ducts) and its velocity. Where the contaminants negotiate a bend, the angle of the duct must not affect the airflow.
Some LEV systems utilise an air-cleaning system that scrubs or removes the contaminant before its emission into the environment. The term scrubbing usually refers to chemical removal from the airstream. Filtration of dusts is the mechanism for cleaning dusts from the air before being released to the ambient air.

Since LEV systems incorporate forced ventilation, a fan is installed between the hood and emission point. The fan must generate sufficient air velocity within the ducts to capture the contaminant and keep it entrained in the airstream, while achieving the most economical efficiency.

The final component is the stack. A comprehensive discussion of the types of stacks will not be provided in this chapter. Since emission of the contaminant (or cleaned air) occurs to the environment, it is mostly an environmental issue.

The most commonly used document that occupational hygienists have to assist in developing and designing LEV systems is the ACGIH’s *Industrial Ventilation: A Manual of Recommended Practice*. This manual is extensive in its coverage of types of systems, duct design and equations for calculating airflow. For further information about ventilation that is beyond the scope of this chapter, it is strongly recommended that this text be consulted.

**Designing local exhaust ventilation**

When planning to install an LEV system it is first necessary to characterise the emission source, most likely path of exposure and workplace conditions. Questions that could be asked include:

- **Is the contaminant a dust, fume, gas or vapour?**
- **What is the emission rate and velocity of emission?**
- **What cross-draughts or eddies could affect the collection of the contaminant?**
- **Does the LEV need to be portable or fixed in one location?**

Each of the components of the LEV will be considered in turn later in the chapter. It is important to realise that designing a LEV system is not a typical task for an occupational hygienist. However, a team approach incorporating the skills of a ventilation engineer, maintenance personnel and the occupational hygienist should result in optimal outcomes. Each party has individual strengths that they bring to the project.

**Hoods**

The purpose of the hood is to capture and collect contaminants (outside or inside the hood), and draw them into the exhaust for removal. The main categories of hoods are:

- **enclosing hoods**
- **receiving hoods**
- **capturing hoods**
- **push–pull systems**
- **exterior hoods**.

An example of an enclosing hood is a laboratory cabinet, shown in Figure 13.4.

An enclosing hood fully or partly covers the contaminant source or process. For contaminant removal, it is the most efficient. However, it presents problems with access to the process and acceptability for use in the workplace. Some other examples that are commonly used include a glove box for dealing with highly pathogenic biological agents or an abrasive blasting box that uses glass beads to remove rust or paint from small articles.

The receiving hood collects an already moving contaminant by directing it into the hood. It is strategically placed to make the most of the natural velocity of the particle (exerted through mechanical energy or thermal buoyancy). Your local fish-and-chips shop utilises the principles of the receiving hood above the deep fryers. As the oil heats, it emits...
a myriad chemical contaminants including polycyclic aromatic hydrocarbons. The heating process causes an upward movement of these gases and vapours into the overlying hood.

A capturing hood reaches out to pull the contaminant towards it. Some examples are the:

- **downdraft hood**
- **slot hood**
- **high-velocity, low-volume system.**

The downdraft hood is mounted underneath a contaminant to capture the contaminant through a wire screen or plate with holes. Some high-risk welding operations such as manganese welding use a portable hood that is sited close to the fume-generating area. The contaminant is induced into the hood by its high velocity.

Another example is the ‘push–pull’ ventilation system that can be installed over solvent baths. On one side a slot hood is designed to force air over the liquid, and at the other end the exterior hood collects the contaminant-laden air for removal.

An exterior hood is usually located close to the contaminant source, while not actually enclosing it, for instance, a hand-held sander with attached LEV and filter.

**Capture velocity**

The capture velocity refers to the velocity of air required to sufficiently induce contaminant air into a hood and exhaust it within the system. The capture velocity differs depending upon the nature of the contaminant, its emission velocity and air currents which may affect its motion.

For instance, contaminants released with virtually no velocity into quiet air (such as evaporating materials) require a capture velocity of 0.25–0.5 m.s\(^{-1}\) compared with contaminants released at high velocity into a zone of very rapid air motion (e.g. grinding or abrasive blasting) which require a capture velocity of 2.5–10 m.s\(^{-1}\).

While this sounds relatively simple, the problem of capture velocity is quite complex. Chapter 4 provides a description of the characteristics of dusts, including their momentum, inertia and density. Velocity contours and flow direction lines are used to predict the best type of hood to use in a particular application. The velocity of flow along the centre line of a plain hood can be expressed by Equation 13.9.

**Equation 13.9**

\[
v = \frac{Q}{10X^2} + A
\]

Where:

- \(v\) is the air velocity (m.s\(^{-1}\))
- \(Q\) is the airflow rate (m\(^3\).s\(^{-1}\))
- \(X\) is the distance from the hood (m)
- \(A\) is the hood cross-sectional area (m\(^2\))
Examination of Example 13.4 and Example 13.5 illustrates that higher velocities are obtained from a circular shaped hood, rather than one with a square opening. Minimising cross-draughts will further assist the capture velocity. Opposing air currents cause cross-draughts. By utilising a number of slots or a flange, the airflow can be greatly improved.

**Example 13.4**

A contaminant is being drawn into a plain square hood with a length of 30 cm. If $Q$ is $5 \text{ m}^3 \text{s}^{-1}$, what is the air velocity at 5 cm, 10 cm, 20 cm and 1 m from the hood?

Answer:

\[ v = \frac{Q}{10\pi^2} + A \]

- At 5 cm, \( v = 43 \text{ m.s}^{-1} \)
- At 10 cm, \( v = 26 \text{ m.s}^{-1} \)
- At 20 cm, \( v = 10 \text{ m.s}^{-1} \)
- At 1 m, \( v = 0.5 \text{ m.s}^{-1} \)

**Example 13.5**

A contaminant is being drawn into a plain circular hood with a radius of 15 cm. If $Q$ is $5 \text{ m}^3 \text{s}^{-1}$, what is the air velocity at 5 cm, 10 cm, 20 cm and 1 m from the hood?

Answer:

\[ v = \frac{Q}{10\pi r^2} + A \] (Note: \( A = \pi r^2 \))

- At 5 cm, \( v = 52 \text{ m.s}^{-1} \)
- At 10 cm, \( v = 29 \text{ m.s}^{-1} \)
- At 20 cm, \( v = 11 \text{ m.s}^{-1} \)
- At 1 m, \( v = 0.5 \text{ m.s}^{-1} \)

**Flanges**

In its simplest form, a flange is a surface that lies parallel to the hood face. Its purpose is to prohibit unwanted air from behind the hood from flowing into the hood. Therefore, the flange will increase the effectiveness of airflow rate by carefully directing contaminated air from in front of the hood.

From Equation 13.9, we can see that the flange can do either of two things:

- **increase air velocity** (in effect, this means that to achieve a required airflow rate, \( Q \), the capture velocity may be significantly improved by adding a flange)
- **decrease the airflow rate required to achieve a particular capture velocity at a given point.**

**Slots, baffles and plenums**

Exterior hoods are often designed to incorporate slots, baffles and plenums. Slots are essentially openings that have a length to width ratio of 0:2 or less. The benefit of slots is that they reduce turbulence and allow for a more uniform airflow. They are often used where it is important to minimise the occurrence of eddies or excessive evaporation of a contaminant. A plenum is usually incorporated with a slot to assist in the uniform distribution of air.

Baffles are similar to flanges, except that they restrict airflow from the front or sides of the hood. This means that the area available for airflow is restricted and any air sucked through the baffle increases in velocity and can be easily directed through the LEV system. The basis for this theory lies with Equation 13.1 \((Q = vA)\). So, to maintain a constant airflow rate, velocity increases as the area decreases.

**Ducts**

After identifying the type of contaminant that will be drawn into the hood and through the LEV system, the next step is to decide on the duct construction, shape and diameter. Consideration should be given to the type of material from which the duct is constructed. Some materials may be rigid (such as aluminium or other metals) while others may be flexible — these are generally used where the LEV is movable and can be located at different workstations.

The selected duct diameter and shape will depend on the type of contaminant that is
being transported and the required duct transport velocity. For instance, circular ducts are best for transporting aerosols, resist collapse and can be made from lightweight materials without failure. They also have less internal friction than other shapes such as squares and rectangles.

The process for selecting appropriate duct diameters is to consider the required velocity for a known contaminant (available from the ACGIH’s *Industrial Ventilation: A Manual of Recommended Practice*) and then use Equation 13.1 to calculate the required area. Depending on whether a square, rectangular or circular duct is chosen, this can then be extrapolated back to the dimensions of the duct.

**Example 13.6**

If an LEV system required a duct with an area of 0.3 m², what diameter of circular and square duct could be used?

**Answer:**

Square duct:

\[ d = \sqrt{A} = \sqrt{0.3} = 0.55 \text{ m} \]

Circular Duct:

\[ d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(0.3)}{3.14}} = 0.62 \text{ m} \]

**Fans**

In most situations, a fan provides air movement through the LEV system. Fans consist of a series of blades that are mounted on a rotating shaft usually driven by an electric motor. The main types of fans are:

- **axial flow fans**
- **centrifugal or radial flow fans.**

With axial flow fans the air travels parallel to the fan axis. The blades of the fans can be either propellers (that move large volumes of air but are unable to deal with high resistance) or impeller blades. Impellers can be mounted on the fan axis. A tube axial fan is an example of this.

Centrifugal fans operate using the principle of centrifuge. As air passes towards the blades of the fan, it is rotated at an angle of up to 90 degrees. The advantage of centrifugal fans is their ability to handle large volumes of air. This is achieved through either simple impellers or blades that are curved. The blades can be curved either forwards or backwards.

Forward-curved blade fans usually have many blades placed in an arc configuration. Due to this configuration, the air is accelerated to high velocities and the fans are especially useful for moving great volumes of air. The backward-curved blade fans are most suitable where high-pressure drops occur.

**Stacks and emission points**

Once the contaminant has been collected from the workplace and transported through the ducting, it must be ejected from the workplace. Often, an air-cleaning device such as a scrubber or filtration system may be installed in series with the duct. In other cases, the contaminant-laden air is released directly into the atmosphere. Since the capture velocity of the contaminated air affects its movement and dispersion in the ducts, it is vital that the type of stack that is attached does not affect this.

Some stacks are merely open pipes that allow the contaminant to be forced from them due to the positive pressure after the fan. It is generally accepted that the stack should be located at a height at least equal to the highest point of the building. If the stack is not high enough, the contaminant could be caught in turbulent eddies surrounding the roof structure and enter the workplace again. In particularly wet conditions, a weather cap or
witch’s hat is placed on top of the stack. This prevents water from entering the stack and ducting. Unfortunately, it also creates turbulence at the top of the duct as it joins the stack. Therefore, the use of this type of cap is not recommended.

Measurement of air velocity and pressure in LEV systems

The fundamental principle of operation of an LEV system is to draw air from one location before transporting it to another for removal. The device that performs this inducement of contaminants in an airstream is the fan. As the fan moves air from one area to another, it causes a partial vacuum or area of lower pressure from where the air has been removed. Due to the nature of gases, air quickly moves into this space.

At the face of the hood, air pressure is slightly less than atmospheric pressure since the fan is sucking air into the hood. Therefore, the outside air will move along this pressure gradient and pass into the hood. As the air passes through the fan the pressure increases, causing the air to move along the path of least resistance until it meets with the stack and is emitted from the duct.

Now imagine the air that is passing through the duct on the stack side of the fan. It has positive pressure. This difference of pressure between the air inside the duct and the ambient air is known as static pressure ($P_s$). Static pressure is perpendicular to airflow movement. As expected, the static pressure is negative on the suction side of the fan. At the outlet side of the fan, it is positive.

The air also places pressure in the direction of the airflow. This is called the velocity pressure ($P_v$). The velocity pressure acts only in the direction of the airflow. It has no effect at right angles to the flow so it does not exert any force on the walls of a straight duct, whereas the static pressure is exerted on the duct and in all other directions as well.

To measure the air pressure, both the static and velocity pressure must be considered. This is known as the total pressure ($P_t$) and is shown in Equation 13.10.

**Equation 13.10**

$$P_t = P_s + P_v$$

Where:

- $P_t$ is the total pressure
- $P_s$ is the static pressure
- $P_v$ is the velocity pressure

A double-tubed probe called a Pitot tube (Figure 13.5) can be inserted into the wall of a duct and used to measure pressure inside the duct. The Pitot tube is connected to a manometer by flexible tubing and inserted carefully into a hole drilled in the duct. The Pitot tube has holes both at the end of the tube and along its length. As it is inserted into the duct, the Pitot tube can be connected to the manometer in three ways, to measure $P_s$, $P_v$ or $P_t$:

- **The tubing from the manometer can be connected to the outer tube outlet to measure static pressure.** Static pressure will be negative on the suction side of the fan.
- **For velocity pressure, both the inner and outer tubes are connected to the manometer.** Velocity pressure is always positive.
- **For total pressure, the inner tube of the Pitot tube is connected to the manometer.** Total pressure is negative on the suction side of the fan.

If velocity pressure is measured, the velocity of the airstream can be calculated from Equation 13.11.
Equation 13.11
\[ v = \sqrt{2P_v/\rho} \]
Where:
- \( v \) is air velocity (m.s\(^{-1}\))
- \( P_v \) is velocity pressure (Pa)
- \( \rho \) is density of air (1.2 kg.m\(^{-3}\))

The force that the air exerts is equal to the kinetic energy of the air. It is often described as the total work done on an object and is equal to its change in kinetic energy. Kinetic energy is determined from the mass and velocity of objects. Therefore, as the velocity of air increases, its kinetic energy also increases.

Other instruments for measuring air velocity

Other measuring instruments that can be used to measure air velocity include:

- **thermal or hot-wire anemometer**
- **swinging vane anemometer**
- **rotating vane anemometer**
- **Kata thermometer**.

Air velocity over a thermal anemometer is measured by a change of resistance in a heated wire sensor. This change is converted to a change in current and electrical signal. Hot-wire anemometers are not recommended in potentially flammable workplaces such as confined spaces or where the contaminant is corrosive or the work environment is dusty. Figure 13.6 shows an example of a hot-wire anemometer.

Swinging vane anemometers are less precise than the hot-wire anemometer. They operate by the displacement of a spring-loaded flap or vane.

The rotating vane anemometer consists of a number of blades that are configured to allow the air movement to rotate them. The number of rotations are then counted over a time period (usually 1 minute). As they are mechanically operated, these are used in underground coalmines to determine the air velocities.

Another device used in ventilation surveys is the smoke tube. While the smoke tube is not used to quantify air velocity, it does allow clearer observations of air currents. An air current smoke tube is shown in Figure 13.7.

Figure 13.5  Pilot tubes
PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment or PPE aims to minimise exposure at the receiver. For this reason, it is found at the base of the hierarchy of control. Depending upon the type and form of the contaminant, PPE has been designed to cover most parts of the body. The parts of the body that can be protected against hazards using PPE are the head, eyes, lungs (respiratory system), ears, feet, skin and hands.

While PPE sits at the bottom of the hierarchy of control, there are times where its use can be justified. For instance:

- when working close to a hazard-generating area or a task that requires the worker to be in the immediate vicinity of the hazard
- sporadic and short duration exposure to hazard
- for work where the location continually changes
- where engineering controls would result in unreasonable expense
- in emergency situations or rescues.

Respiratory protection equipment

Respiratory protection equipment or RPE is likely to be the main form of personal protective equipment worn to reduce exposure through inhalation. Unfortunately, RPE is often used the least effectively. The two main types of respirators are the air-purifying respirator and air-supplied respirator.

Air-purifying respirators

These are probably the most common respirators. The underlying assumption with air-purifying respirators is that there is an adequate supply of oxygen (>19.5 per cent). A filter or chemical adsorbent is used to remove the contaminant from the air the worker is breathing. As such, there are a few limitations with this style of RPE:

- they can only be used where there is enough oxygen to sustain life
- there are problems with ‘break-through’ of contaminants
- adsorbing materials are specific to the contaminant to be removed
- they are not to be used for very toxic or extremely high concentrations of contaminants
- problems with fit may occur.

The three main types of air-purifying respirators are:

- non-disposable air-purifying respirators with disposable cartridges
- disposable air-purifying respirators
- powered air-purifying respirators (PAPR).

Non-disposable air-purifying respirators usually consist of a face-piece with filtration cartridge (filter) that is replaced once its life has expired. The cartridge is screwed or snapped onto the face-piece and the worker inhales air through the filtering cartridge. Sometimes, a series of cartridges can be fitted to the face-piece to deal with different types of contaminants. This causes a negative pressure inside the respirator. The face-piece can either cover the entire face (full-face) or half of the face (half-face). A half-face mask covers the mouth and nose but leaves the eyes open to the environment. A full-face mask covers the entire face including the eyes. It is suitable where eye protection in addition to respiratory protection is required.

Face-pieces are usually available in several sizes and are manufactured from a variety of materials, the most popular of which are rubber
Figure 13.6  A hot wire anemometer

Figure 13.7  Air current tube
and silicone. These styles of respirators are termed ‘non-disposable’, since the face-piece is not disposed of. After a time, the filters must be replaced and regular maintenance performed to ensure the mask does not have any leaks or has not deteriorated in any way.

Both the half-face and full-face respirators can be uncomfortable and cumbersome. They are particularly ill suited for hot and humid conditions. Several types of respirators have one-way exhalation valves incorporated into the design of the face-piece. This aims to dissipate heat and water vapour inside the mask. However, in hot and humid conditions it is not uncommon for the mask to fog up and become filled with perspiration and water vapour. Others have speech valves that allow the workers’ voice to be less muffled than when wearing traditional face-pieces.

Another type of air-purifying device is the disposable respirator. As the name suggests, these are worn for a limited period before the entire respirator is thrown away. Disposable respirators have a limited number of contaminants that can be removed; therefore, their use is mostly limited to the removal of dusts, fume and organic vapours. The respirator is constructed to be a semi-rigid shape that can either be free form or have a supporting mesh to maintain its structure. The main types that we see in Australia are shaped as a hemisphere or designed to fold flat.

Powered air-purifying respirators are similar to the non-disposable respirators in that they have a face-piece with replaceable filtration cartridge. However, instead of the person breathing through the filter, a pump pushes air through the filtration media. The pumps are usually located on the belt at the back of the worker or in the helmet itself. The disadvantage of these types of respirators is that they must have a sufficient battery life to support the pump operating over the entire shift. They must also be suited to the work; for instance, if welding is being performed then the helmet will need to be shaded.

### Filters

The filtration of contaminants from the air occurs through a filter or adsorbent material. Filters for dust, fumes and mists contain fibrous materials which mechanically remove the particles from the air. Some filters operate through the use of an electrostatic fabric that can trap particles smaller than the mesh of the fabric itself. Gas and vapour filters contain adsorbents, such as activated charcoal, which react with and remove particular chemicals.

AS/NZS1716 divides the filtration efficiency of particulate (or dust) filters into the following three groups:

- **Class P1**: for use against mechanically generated particles
- **Class P2**: for use against mechanically and thermally generated particulate
- **Class P3**: for use against all particulate including highly toxic materials.

Class P3 filters only offer their high-filtration efficiency when used with a full-face respirator or powered air-purifying respirator.

Gas and vapour filters are classified according to the substance they protect against and their capacity. Caution should be exercised in the use of gas and vapour filters. Many of these substances have odour thresholds at levels that are significantly higher than the occupational exposure standard. In such cases, it is not advised to use air-purifying respirators where the substance cannot be detected through smell or taste at a level lower than the occupational exposure standard. Their application should be limited to exposure situations where:

- the substance has a distinguishable odour or taste well below the occupational exposure standard
- the substance presents a relatively...
low risk in terms of adverse health effects

- the adsorbent material is compatible to the substance being removed from the atmosphere.

AS/NZS1716 specifies a classification system for gas and vapour filter capacity and type. The capacity of filters is shown below. Class AUS has the lowest capacity and Class 3 the highest.

- Class AUS
- Class 1
- Class 2
- Class 3.

The specific types of cartridges are:

- **Type A** (specified organic vapours)
- **Type B** (inorganic and acid gases, except carbon monoxide)
- **Type E** (specified inorganic and acid gases such as sulphur dioxide, except carbon monoxide)
- **Type G** (low vapour-pressure chemicals such as agricultural chemicals, not for carbon monoxide)
- **Type K** (ammonia and ammonia derivatives)
- **Type MB** (methyl bromide)
- **Type AX** (specific types of low boiling point, less than 65°C, organic vapours)
- **Type Hg** (mercury vapour)
- **Type NO** (oxides of nitrogen)
- **other specific types that do not fit into other categories.**

Some filters will be a combination of both particulate and gas filters. With these, the individual cartridges are placed in series or the face-piece may allow two cartridges to be attached.

**Filter life**

It is virtually impossible to predict the life of a gas or vapour filter. Several factors impinge on its life, including the concentration of contaminant, exposure to multiple substances, ventilation rate, storage conditions and capacity of the filter.

What is known, however, are that such air-filtering cartridges do have a finite life. As the contaminant adsorbs onto the chemical sorbing material, it reduces the number of areas available for adsorption. Adsorbing materials such as activated charcoal have an affinity for contaminants such as organic vapours due to their polarity or electron-attracting powers. Unfortunately, water is also particularly polar and adsorbs to the activated charcoal. This is significant where the air-filtering media is left exposed to humid air which can cause a reduction in the life of the filter. For this reason, chemical cartridges should be opened immediately before use. At the end of the shift (or exposure), they should be placed in a sealed plastic bag to prevent water vapour from the atmosphere adsorbing to the adsorbent material. As a maximum, filters should be discarded no longer than six months after opening.

Many respirator manufacturers and suppliers now provide advice about the type and life of respiratory protection devices. Some have also developed software that can be used to estimate the life of respirators. A useful Internet website for this is the 3M website (www.3m.com), where the program can be downloaded. The program allows the user to insert the name or chemical abstract service (CAS) number of the substance and expected concentration. It then suggests a variety of respiratory protection devices and cartridges. Once these have been chosen, the temperature, atmospheric pressure and work rate are entered into the program. The user specifies a breakthrough level, and the program calculates the estimated service time.
While this is a US program, the only alterations that may need to be made are related to the occupational exposure standards.

**Air-supplied respirators**

The main types of air-supplied respirators that are used at the workplace are:

- **air-hose respirators**
- **air-line respirators**
- **self-contained breathing apparatus (SCBA)**
- **oxygen-producing devices.**

Air-hose respirators are usually supplied with air from a natural or continuous flow that is attached to a full-face face-piece respirator fitted with a wide diameter breathing tube and exhalation valve system.

Air-line respirators consist of a full-face, half-face or head covering respirator, which is supplied with compressed air continuously. Abrasive blasting usually uses this type of respiratory protection.

SCBA has a self-contained supply of air or oxygen, which removes the need for a hose or air-line. Firefighters and emergency rescue operations usually use the SCBA.

Oxygen-producing devices have been used for many years in emergency situations such as underground coalmine evacuations where combustion may have occurred, releasing carbon monoxide. They are often known as self-rescuers and are single-use, self-contained oxygen-generating respirators. The self-rescuers provide a finite oxygen supply, with the latest styles generating oxygen on demand. This occurs by a closed-circuit system. When the self-rescuer is activated, an immediate oxygen source is generated (usually by chlorate candle). The second source of oxygen is potassium superoxide (KO₂). As carbon dioxide and moisture from the exhaled breath react with the KO₂, oxygen is formed.

**Implementing a respiratory protection device program**

As with any form of control, a systematic approach to the implementation and use of respiratory protections is advised. The respiratory protection device program would be incorporated into the occupational hygiene or occupational health and safety management system of the organisation (Chapter 14). Ideally, the system would include:

- **standard operating procedures for the selection and use of respirators**
- **a written plan on how the program will be administered and the responsibilities of personnel**
- **an assessment of occupational hygiene hazards that may be controlled through the use of respiratory protection**
- **guidelines for selecting the most appropriate type and capacity of respiratory protection devices**
- **a training program that includes hazard identification, health effects from exposure to the contaminants being controlled and maintenance, fit, cleaning and inspection of the respiratory protection devices**
- **where appropriate, health surveillance of workers.**

**Selecting respiratory protection**

The selection of an appropriate respiratory protection device is dependent upon the hazardous substance the individual is exposed to — its nature, chemical composition, concentration and form (e.g. gas or vapour). It may be necessary to conduct atmospheric monitoring prior to determining the most appropriate form of protection. When deciding to use respiratory protection, it is imperative that it is:
• carefully selected for the individual worker and task for which it is intended to be used
• readily available and used when needed
• clean and operational
• maintained by appropriately trained personnel.

In its selection, it is also important to consider the type of work — its physical demands, including workload, heat and movement requirements, and the need to wear other forms of personal protective equipment. AS/NZS1715 should be referred to, as it provides a flow chart that must be used in conjunction with tables of respirators and filter types.

When selecting a respirator, the protection factor and required minimum protection factor (RMPF) should be determined. The protection factor (Equation 13.12) is defined as the expected reduction in exposure that should be provided by a particular respirator.

\[
\text{Equation 13.12} \\
\text{Ambient air concentrate} \\
\text{Concentration in respirator}
\]

The RMPF (Equation 13.13) is the factor by which the exposure of the wearer must be reduced to ensure the concentration of contaminant inside the respirator is equal to or less than the occupational exposure standard.

\[
\text{Equation 13.13} \\
\text{RMPF} = \frac{\text{Ambient air concentration}}{\text{Occupational exposure standard}}
\]

RMPF is measured in laboratory conditions and does not provide a good indication of the actual protection which is likely to be achieved in the workplace due to facial fit (e.g., sideburns, beards and unusual facial features will affect the fit) and other conditions such as heat and humidity.

\text{Maintenance, repairs and cleaning}

When respiratory protection becomes relied upon as a control measure, regular maintenance must be conducted to ensure its integrity. All respirators must be inspected for wear and deterioration of their components before and after each use. Except for disposable respirators, attention must be given to rubber or plastic parts of the face-pieces. This is especially applicable to the face seal surface, headband, valves, connecting tube, fittings and cartridge. The connections should also be firmly tightened. Gas and vapour cartridges must be replaced as necessary to provide complete protection. It is best to follow the manufacturer’s recommendations and seek advice when uncertain of the service life of the cartridge. Mechanical filters must be replaced as necessary to avoid high resistance to breathing.

Emergency-use respirators (such as self-rescuers) and SCBA must be inspected at least monthly. In this inspection process, the air and oxygen cylinders must be fully charged according to the manufacturer’s instructions. The regulator and warning devices are also checked to ensure they are operating correctly. It is diligent to maintain records of the inspection dates and findings. If a fault or defect has been discovered, only experienced people should repair the respiratory protection devices.

For hygiene reasons, workers should clean their own respirators or a system should be implemented in the workplace to ensure they are cleaned and disinfected. This is especially important where the use of respiratory protection devices is limited and a worker may not have their own equipment. For storage, many manufacturers suggest that the respirators need to be stored to protect against dust, sunlight, heat, extreme cold, excessive moisture or damaging chemicals.
Cartridges should be placed in a plastic bag to prevent undue adsorption onto the filter.

**Training**

In order for workers to understand why they are being asked to wear respiratory protection devices, they should be informed of how to select, use and maintain the respirators. As a minimum, the training should include:

- **how to recognise occupational hygiene hazards**
- **the possible consequences of exposure to the hazard if respiratory protection devices are not used**
- **an explanation of why the controls towards the top of the hierarchy of control are not viable**, but with a commitment that alternative control methods are being pursued
- **details about the capabilities and limitations of the respiratory protection devices**
- **instruction and hands-on training about how to use the devices**, including supervision to ensure that they continue to be properly used.

**Hand protection**

Gloves and mittens are a form of PPE which are often used when handling hazardous substances, infectious wastes or hot materials. When choosing gloves, consider carefully the extent of protection required, size and the amount of flexibility and dexterity that is required.

For hazardous substances, the best information source to determine the correct type of glove is the material safety data sheet. It should specify the type of material and size of glove that is appropriate. The choice of glove for protection against chemicals requires knowledge of the chemicals to be handled and the resistance of the glove material. Gloves must be able to resist permeation, degradation and damage.

The main materials used in the construction of chemical protection gloves are:

- nitrile
- rubber
- PVC
- neoprene.

If information about insulating gloves for electrical purposes is required, AS2225 should be perused. The AS/NZS2161 series provides advice about occupational protective gloves generally, for mechanical risks and for cold. The full bibliographic details are included at the end of this chapter.

While it is important to choose the correct glove to protect against a hazard, comfort must not be forgotten. For instance, if the hands inside gloves become extremely hot and

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**Case study 13.4**

A worker at a silica mine is exposed to crystalline silica (assume quartz) at a concentration of $0.8 \text{ mg.m}^{-3}$. The NOHSC occupational exposure standard for quartz is $0.2 \text{ mg.m}^{-3}$; therefore the RMPF is $= 4$. Since the quartz dust is mechanically generated (as opposed to thermally generated) we should refer to AS/NZS1715 where we will find that the most suitable respirator is:

- P1, P2 or P3 filter with half-face face-piece — replaceable filter or disposable face-piece
- half-face-piece air-line respirator—negative pressure demand
- P1 filter in PAPR with any head covering.
sweaty, they are less likely to be worn. Similarly, if workers feel they are unable to obtain an adequate grip of a tool or equipment, they may prefer not to wear the glove or mitten. All of these must be taken into account in the selection of hand protection.

**Eye protection**

While eye protection is recommended for use when handling many types of hazardous substances, it does come with the following limitations:

- the lenses and shields may become scratched or dirty
- the lenses and shields may become foggy
- the lenses and shields may restrict vision due to distorted vision
- it is often hard to use eye and face protection when wearing prescription glasses
- the attenuation of hearing protectors may be affected.

The main types of eye and face protection that would be used to protect against the harmful effects of hazardous substances include spectacles, goggles, face shields and hoods or helmets.

AS/NZS1336 gives guidelines on recommended practices for occupational eye protection. Where hot work such as welding or cutting is performed, the eye protection must contain filters to protect against non-ionising radiation. The AS/NZS1338 series specifies the required filters for this protection. AS/NZS1337 is also a useful reference in the selection of eye protection for workplaces.

**Foot protection**

Safety footwear is designed to protect against chemical substances, as well as protect against impact from materials. AS3765 provides detail on chemical resistance where the footwear forms part of a suit. The soles of safety footwear are usually made from hard-wearing materials such as polyurethane or nitrile. They are slip-resistant and provide insulation against temperature extremes and electricity. AS/NZS2210 describes the type of footwear incorporating a steel toecap. Debate still continues about whether toecaps are recommended in all workplaces. As a general rule, steel-capped footwear is advised where objects may fall on the foot and would cause damage. Some incidences of amputated toes have occurred where an object impacted on the footwear, causing the cap to depress and cut the toes. The specifications for impact resistance (in Joules) of safety footwear are given below:

- Type 1 (heavy) — 200 J
- Type 2 (medium) — 130 J
- Type 3 (light) — 80 J
- Type 4 (waterproof) — 200 J.

When selecting safety footwear, both the aesthetic and safety components must be considered. The questions that should be asked include:

- Is the footwear comfortable?
- Will the workers appreciate its appearance and style?
- How resistant is the material to water and chemicals?
- Are a variety of fittings available?
- What forces are likely to impact on the foot?

**Coats, suits and overalls**

A variety of materials are used to protect the body against hazardous substances, in a similar way to the protection of hands. Clothes may be used to protect against chemical agents such as corrosives or solvents or physical hazards such as irritant dusts (e.g. fibreglass, rock-wool, ceramic fibres), fire, heat and general abrasion.
caused through mechanical irritation of dirt or other substances.

Chemical protective suits have a classification, which is detailed in AS3765. This can either be in the form of a breakthrough time or based on the extent to which the external environment is excluded. The main types of suits that are available are gas-tight suits, air-line ventilated suits and full splash suits for dealing with chemicals.

**SUMMARY**

Controlling occupational hygiene hazards is an integral component in managing risk. The hierarchy of control may be used as a guide to select controls that are practicable, cost-effective and minimise risk.

The hierarchy begins with elimination; then substitution; engineering controls such as ventilation, isolation and guarding; administrative controls; and personal protective equipment. As much as possible, controls should be selected from the top of the hierarchy of control. However, in certain circumstances, the use of personal protective equipment may be the only option open to workplaces.

**BIBLIOGRAPHY AND FURTHER READING**


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Chapter 14

Using a systematic approach to risk management

Since this book was first published in 1999, much progress has been made in Australia to use a planned or systematic approach to managing risk. Legislative changes in some States and Territories have all but required that organisations implement an occupational health and safety management system (OHSMS). Indeed, many workplaces that choose to participate in schemes to self-manage (and self-insure) workers’ compensation risk do so with the mandatory implementation of an OHSMS.

This chapter attempts to describe the philosophy of management and practical ways to best deal with occupational hygiene hazards. The chapter asks why, how and what occupational hygienists manage, and describes a systems approach to managing risks with reference to AS/NZS4801.

MANAGING AND MANAGEMENT

What is management? Historically, management has been studied and approached from a business perspective. Management can be described as the techniques that an organisation uses to plan, lead, control and organise. Management principles are applied so that an organisation can succeed and adapt in a continually changing environment. While there are many management theories that have derived over the decades, it has taken considerable time for these to be embraced and applied to the management of occupational hygiene hazards. However, now more than ever, the importance of integrating an occupational hygiene program within the organisation’s existing management system is paramount. To do this we focus on managing people, resources and time. Indeed, the theory of risk management adopts such an approach, which consists of:

- anticipation
- recognition
- evaluation
- control.

In Australia, the principles and practices of risk management are explained in AS/NZS4360: 1999. Indeed, many organisations use the methodology and tools suggested in this standard to identify hazards, assess the level of risk and prioritise controls.

THEORIES OF MANAGEMENT

Management theories have been used to describe the relationship between workers and their role in the cycle of production or employment. This in turn governs the way their activities are organised for optimal
performance. While the term performance may appear a little harsh, it should be noted that a number of factors impinge on performance. It encompasses workers’ production capacities in addition to personal issues such as morale, satisfaction and motivation.

Frederick W. Taylor (1856–1915) suggested a scientific management theory that describes the worker as a component of a production system. He suggested that there was only one efficient way to perform a job. Taylor’s theory (Taylorism) related to workflow and involved segmenting a large task into smaller repetitive ones. The workflow was designed so that the worker, tools and process were selected for each specific task. Taylor theorised that work and responsibility were equally divided between management and the workers, with management taking over work for which it was more suited.

Around the same time, administrative theorists developed theories of what managers do and what constitutes good management practice. Henri Fayol (1841–1925) and Max Weber (1864–1920) are the most famous of these theorists. Fayol proposed the following principles of management:

- division of work
- centralisation
- authority
- straight-line chain of authority
- discipline
- order
- unity of command
- equity
- unity of direction
- stability
- inattention to personal need and interests
- initiative
- remuneration
- team spirit.

Weber was the first to suggest that bureaucracy was the optimal form of organisation. In his ideal bureaucracy, there was an authoritarian hierarchy, division of labour, formal rules and regulation, formal selection, separate career orientation for managers and no attention given to personalities or individualism.

Later, a more behavioural approach caused a review of the scientific and administrative theories that considered the individual. This was the real birthplace of industrial psychology and considered issues such as motivation, group dynamics, leadership and communication. Recently, more emphasis has been placed on a systems approach. This approach argues that an organisation is a set of interrelated and interdependent parts. Each of these parts impacts on the others and needs to be considered in decision-making.

**REASONS FOR MANAGING OCCUPATIONAL HYGIENE RISKS**

**Financial costs**

While the selection and implementation of a holistic or systems approach requires commitment and ongoing support, the outcomes of success are certainly worth the effort. For many managers, the main impetus of managing occupational hygiene hazards is financial. Adverse exposure to an agent may result in lost time from work and cost an organisation through medical expenses. However, this is a simplified view of the real costs of workplace injury and disease from exposure to occupational hygiene hazards. Since the latency period of many agents is years or decades, the individual, community and other employers may absorb the costs. There have been a number of estimates relating to the total costs in Australia because of poor performance in the area of occupational health and safety.

In 1994, Worksafe Australia put the annual
cost (in 1992–93 dollar terms) at between $14.9 billion and $37.2 billion (Foley et al. 1995). This converts to between $16.2 billion and $40.5 billion in 1995–96 dollar terms if the consumer price index is used as the inflator. In September 1995, the Industry Commission estimated the annual cost of serious cases as $20.1 billion, in 1992–93 dollars (approximately $21.9 billion in 1995–96 dollar terms). The costs of inappropriate risk management can be categorised according to the parties who are burdened with the cost, chiefly the individual, workplace and community (Table 14.1).

While these costs do not all represent immediate financial losses, they reflect on the overall impact of failing to manage risk.

**Ethical reasons**

Ethics refers to the morality associated with a particular event or situation. It is based on an individual or societal perception of what is right and worthy. Management of occupational hygiene risk is viewed by society as an ethical issue since the actions of an employer are seen as immoral if they do not control exposure to agents that may harm workers’ health. Just as consumers or clients have boycotted organisations or companies because of their environmental records or stance, a similar viewpoint is being taken against encroachments on workers’ health.

**Industrial relations reasons**

Industrial relations refers to the ongoing dynamics between workers (and their representatives) and the employer. Australia has a long history of confrontation between workers and employers about many issues (health and safety included).

A systematic approach to managing
occupational hygiene hazards at work will assist in reducing disputes and aid consultation between the parties.

**Legal reasons**

Australia’s legal system is divided into the following types of law: statute and common law.

All of Australia’s States and Territories and the Commonwealth have statute legislation that protects workers by minimising risk. In these Acts, duties of care or obligations are imposed on parties who may cause or be affected by hazards in the workplace or work-related activities. If these laws are breached, severe fines and even imprisonment can result (depending upon the Act).

Management of risk forms the cornerstone of these pieces of statute legislation. The onus for management lies chiefly with the employer, but manufacturers, designers, suppliers, importers, other people and workers may also have duties. The legislation is based on the concept of self-regulation, whereby the workplace is responsible for identifying, evaluating and controlling risks.

The other type of law is common law. The precedence set by judges’ determinations form the basis of common law. Under common law every person has a duty not to commit a ‘wrongdoing’, also known as a tortious act. For such an action to be brought against a person, the incident must have been reasonably foreseeable or able to be controlled and a cause–effect relationship proven.

Effective management of occupational hygiene risks can minimise the likelihood of prosecution under either common or statute law.

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### Case study 14.1

An analytical laboratory uses acid in chemical reactions. A worker suffers a burn from exposure to the acid. The immediate losses from such an incident include:

- lost time from work
- first-aid treatment time
- transportation of injured worker to medical facility
- workers’ compensation and rehabilitation costs
- loss of product due to spillage
- reduction in production due to time taken to attend to injured worker
- time to complete incident reporting form
- first-aid equipment costs.

Some other ‘hidden’ sources of loss may occur from:

- reduction in morale of fellow workers
- animosity towards management that the incident occurred (could lead to sabotage or ‘work-slow’ by workers)
- increased workers’ compensation premiums
- increased burden on community resources such as the health care system, disability pension
- replacement of injured worker
MANAGING AND MOTIVATING PEOPLE

Achieving the aims of an occupational hygiene management system will require a consolidated approach that integrates policies, procedures, benchmarked standards and performance reviews. However, it is important not to miss the most important spoke in this wheel — people. Without the support of management and workers, the best-laid plans for occupational hygiene and risk management will fail.

Classical management theorists such as Taylor asserted the philosophy of scientific management, where a natural ‘cooperation’ between workers and management was deemed to be the best way to achieve outcomes. In this way jobs were scientifically analysed and workers were specifically selected for a job and provided with only enough training to ensure the worker and the job ‘fitted’. Fayol identified the major management functions as planning, organising, commanding, coordinating and controlling. The late nineteenth century saw the application of psychological research to workplace relations. Elton Mayo (1880–1949) studied the satisfaction of worker needs and productivity and concluded that workers reacted positively to management concern.

More recently, the contingency approaches to management have been developed, emphasising the difference between organisations and their cultural environment. Writers such as Henry Mintzberg and Kenneth H. Blanchard maintain that each organisation requires its own approach and that theories of management may not apply in every situation. This acknowledges that not all workplaces are alike. Similarly, not all workers think in the same way.

Motivation is a factor that will impinge on the ability to achieve and sustain change, as it relates to the management of occupational health and safety. Motivation can be thought of as the inclination to input effort in order to achieve organisational goals, combined with the potential to satisfy individual need.

A need is a feeling of requirement, which makes certain outcomes appear enticing. For instance, the need to eat and drink, to be secure from physical harm or to belong. The best-known behavioural theory of motivation is probably Abraham Maslow’s Hierarchy of Needs theory, where he hypothesises that every human has five needs. In order of preference, these are:

1. Physiological needs — hunger, thirst, shelter, sexual drives and other bodily needs.
2. Safety needs — security and protection from physical and emotional harm.
3. Social needs — affection, a sense of belonging, acceptance and friendship.
4. Esteem needs — internal esteem factors such as self-respect, autonomy and achievement; and external esteem factors such as status, recognition and attention.
5. Self-actualisation needs — growth, achieving one’s potential and self-fulfilment; the drive to become what one is capable of becoming.

Source: Robbins & Mukerji (1994)

There are several other motivational theories, including Douglas McGregor’s Theory X and Theory Y, which define human nature either negatively (Theory X) or positively (Theory Y). The theories contend that:

- management’s view of the workforce is tainted by its assumptions
- management’s behaviour towards workers accords with these assumptions.

The motivation–hygiene theory by Frederick Herzberg describes intrinsic and extrinsic factors that are related to job satisfaction.
Motivators include achievement, recognition, responsibility, advancement and growth, and contribute to job satisfaction. Hygiene factors include company policy, salary, status and security.

**Some suggestions for motivating workers**

So far, we have identified the basic needs that can affect a person’s motivation. The question arises, once we understand the factors that affect motivation, how do we actually motivate workers? One suggestion is to recognise that each person has different needs, attitudes and personality. Workers may not have the same views or expectations as others. It therefore follows that this recognition of individual differences can be positively used to consider the way workers are managed.

Secondly, people should be matched to their job. For instance, a person who is a ‘high achiever’, with high expectations of themselves, will perform best in an autonomous and challenging job. This links closely with the goals of the individual. The goals are best aligned with the abilities of the worker, the amount of feedback they require and whether they perceive the goals as achievable.

Finally, equity and performance rewards are two issues that can improve motivation. If workers perceive their rewards or outcomes are equal to the inputs (e.g. skills, experience, responsibility, abilities and effort), and are linked to performance, they are more likely to be motivated. Similarly, money should not be ignored. While money is not the only reason for working it certainly is a large sweetener, and without adequate remuneration motivation may suffer.

**Dealing with conflict**

One of the most important skills that an occupational hygienist or risk manager could have is the ability to deal with conflict. Whether the conflict originates from management or with workers and unions, its effective resolution will avoid confrontation or subtle interference such as ‘work-slow’ or ‘work-to-rule’. The term conflict means perceived incompatible differences that result in some form of opposition or interference.

However, not all conflict is a bad thing! The traditional view of conflict is that all conflict is bad and should be avoided. However, the current theoretical perspective on conflict is the interactionist view of conflict. This contends that conflict is necessary for an organisation to perform effectively. While this view does not propose that all conflict is good, certain functional conflict can be valuable. Conflict that supports an organisation’s goals can actually improve the organisation’s performance by keeping the workplace viable, self-critical and creative.

The next issue to remember when handling conflict is that not every conflict justifies action. Some situations may not warrant attention, while others may be too difficult to resolve. Similarly, the people involved in the conflict may have hidden agendas or beliefs that are difficult to rationalise. It is vital that the players and the source of conflict are understood before jumping into the situation. Conflict doesn’t just ‘happen’. Often, disagreements have ‘festered’ over a time and could have occurred as a result of differences in communication, fundamental goals or objectives within the organisation or personal differences.

Finally, dealing with conflict requires knowledge of techniques to manage the situation. The five main approaches are similar to the techniques used for communicating risk discussed in Chapter 12. The options are to:

- avoid
- accommodate
- force
- compromise
- collaborate.
Avoidance of the situation may be best where the conflict is trivial, the conflicting parties are particularly emotional or upset or where the action is not beneficial or outweighs the initial dispute. Accommodation frequently occurs where the issue is not particularly important to one party, and in order to maintain harmony the views of the other party are accepted. If force or authority is used to resolve conflict, the action may be unpopular and result in a lose–lose situation. Compromising asks each party to give up something of value to negotiate a peaceful outcome. Collaboration is the preferred option with a win–win situation resulting. This comes from open and honest discussion between the groups that attempts to find a solution that advantages both parties.

**MANAGEMENT SYSTEMS**

**What is a management system?**

Successful management does not just magically occur. It takes considerable skill and ability in addition to a framework or structure that ensures a logical progression and review of performance. The occupational hygiene program should be integrated into the organisation’s overall management plan and strategies.

Over recent years, organisations have seen the benefits of implementing occupational health and safety management systems. Many companies have adopted the framework identified in AS/NZS4801, which was released in 1999. This standard holds similar principles to that of ISO9001 and ISO14001 (quality and environmental systems, respectively) with a focus on setting policy, planning, implementing the systems, monitoring and reviewing their effectiveness and feeding the learnings through the system for continual improvement.

AS/NZS4804: 2001 accompanies AS/NZS4801 with practical guidelines for implementation. It defines an occupational health and safety management system as:

that part of the overall management system which includes organisational structure, planning activities, responsibilities, practice, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining OHS policy, and so managing the OHS risks associated with the business of the organisation.

Therefore, the management system incorporates the core areas of risk management but also provides a framework to plan, lead, organise and control the occupational hygiene hazards at work.

**Step 1: Starting at the beginning**

In adopting a holistic approach to managing risks, it is imperative that the system is based on a solid foundation of support and commitment with adequate resources for the development, continuation and improvement of the system. Without such fundamental assurance, negotiation of even the most basic issues can become difficult. Obtaining such commitment may not be easy. Some factors that may affect the willingness of parties to agree to the principles within the OHSMS include:

- lack of trust with or from management
- previous difficulties in negotiating occupational hygiene issues
- ‘do as I say, not as I do’ mentality
- insufficient resourcing of similar initiatives
- paternalistic or autocratic management style
- culture of workforce, including a ‘she’ll be right, mate’ approach
- perceived gains or losses to conditions and wages.
Overcoming these barriers may be difficult and take time; however, patience and continuing discussion will only help in the quest for continual improvement.

**Support, benchmarking and policy**

Where to begin? Having obtained commitment to develop and integrate occupational hygiene into a management system, the next stage is to assess the current state of affairs. This will involve asking the following series of questions about who currently has responsibility for managing risks:

- What resources are allocated?
- What systems are in place?
- Are these systems working effectively?

At this stage, an occupational hygiene audit may be a useful technique to obtain this information. The outputs should include:

- identification of hazards and processes
- a gauge of compliance with legislation
- identification of work procedures (effectiveness and appropriateness) and whether they are followed
- a clear picture of how responsibilities are allocated and whether such performance is reviewed.

This initial review will allow the occupational hygienist or risk manager to benchmark the current system for managing occupational hygiene hazards. This should include reviewing or developing a written policy to show that occupational hygiene management lies within the organisation’s overall plan for managing occupational health and safety risks.

**Step 2: Planning and setting goals**

Management can be approached from two levels: strategic and operational.

Senior management is typically involved at the strategic level, as it requires the setting of targets or objectives for performance. At this point, a SWOT (strengths, weaknesses, opportunities and threats) analysis is usually conducted. The SWOT provides an estimation of potential factors that may influence the success of the organisation.

Operational management refers to the ‘shop-floor’ or implementation of strategies, policies and procedures. Once the existing occupational hygiene and safety management system has been reviewed, the next stage involves planning and setting goals and targets. The issues that may need to be considered in this phase are:

- risk identification techniques
- risk management protocols
- risk control techniques and justification
- setting performance targets that are achievable and measurable
- setting performance indicators
- a method for developing and implementing the management system plan
- allocating financial and people resources for the management system
- identifying legal requirements and accessing information.

Once the opportunities for and threats to the success of the occupational hygiene and safety management system have been identified, it is time to set performance targets that are measurable and achievable. It is ideal to adopt positive goals that encourage continual improvement, rather than negative indicators.
such as lost time frequency rates (LTFR) or lost time incidence rates (LTIR). This area of the system may also be viewed as the function of control. The control process consists of the following aspects:

- establishing the standards of performance
- measuring performance
- comparing the performance with standards
- taking corrective action where required.

Information

An emphasis has been placed on setting performance standards and benchmarking. But where does one find this information? In Australia, we have relatively few information sources compared to countries such as the United States. This is where the Internet has become an invaluable tool in searching for information, communicating with others who share similar interests and sharing information.

In Chapter 3, we identified some sources of information and Internet websites, including Australian State and Territory governments. Some employer organisations, such as the Australian Chamber of Commerce and Industry (ACCI), or their State branches may be able to assist with information. Similarly, union or worker groups might be helpful. In Queensland, the Workers' Health Care Centre was set up especially for workers' health.

Allocation of responsibility

In the planning phase, it is important to allocate responsibilities for occupational hygiene and risk management. This could be through the inclusion of responsibilities in job descriptions and making personnel accountable in their performance reviews.

Step 3: Implementation

Implementation of the occupational hygiene and safety management system will involve a concerted effort and commitment from workers and management. It may be useful to utilise the skills of other professionals to assist with implementation, for instance, using audiologists to test workers' hearing before a hearing protection device program is implemented. Occupational physicians or exercise physiologists could conduct fitness-for-work tests.

Implementation requires particular skills in managing others and ourselves. One factor that could significantly impinge on the effectiveness of the implementation of occupational hygiene and risk management strategies is the organisational culture. Organisational culture can be loosely thought of as the customs, beliefs, practices, traditions, values and ideologies of a group of people.

In applying this definition to the workplace, we can see that there are a variety of factors that will influence the culture, including:

- the organisation’s history
- present management style
- size
- structure
- industrial relations activity
- nature of work.

Managing occupational hygiene risks will require all of these issues to be carefully considered and addressed. The organisation’s strategy must also be understood to take account of the social, economic, political and industrial variables that will overlay the operating workplace.

Motivation and needs of workers can inadvertently affect the best-laid plans for occupational hygiene management. Therefore, it is imperative that strategies for human resource management are developed to deal
with potential barriers. Questions will need to be asked about the approach that is taken to manage risks; for instance, is the approach:

- top-down or bottom-up?
- radical or conservative?
- proactive or reactive?
- compromising or directive?

Top-down or bottom-up?

Pressure from management or workers or both often sways the implementation of strategies for occupational hygiene and risk management. The influence of statutory legislation for occupational health and safety places a heavier emphasis on the employer to manage risks while adopting a consultative approach with workers and their representatives.

The traditional approach to risk management took a top-down philosophy where policies and procedures were formulated by senior management, the occupational hygienist or risk manager. It has been argued, however, that such an authoritarian approach would not be effective since those who are affected by such systems (i.e. workers) do not feel empowered and in control of the risks. Risk perception was discussed in Chapter 12.

Instead, a bottom-up approach involves workers who are more likely to know more than their management about their job skills, workplace design and the inherent work risks. The benefits of using a consultative approach (in addition to meeting legal requirements in most States) include:

- increased commitment from workers
- providing opportunities for workers to expand their skills (multiskilling)
- enabling workers' experience and opinions to count when making decisions
- improved communication between groups in the workplace.

The disadvantages of a bottom-up or consultative approach are:

- it takes more time with a bottom-up approach
- conflicts may occur between parties and require resolution
- strong direction and leadership is required otherwise certain vocal factions may dominate.

Radical or conservative?

A radical approach to occupational hygiene and risk management may be to introduce a new management system into a conservative organisation that places an emphasis on measurable indicators of risk management performance or makes line management accountable. Conversely, a conservative tact might include training workers and management so that they are cognisant of proposed changes and then slowly implement the changes over a period of years, rather than quickly.

Proactive or reactive?

Occupational health and safety legislation requires that a proactive or preventive approach to managing risks be taken. However, the role of the occupational hygienist or risk manager may be restricted to merely reacting or responding to current problems due to a lack of forward planning or minimal resources or vision. This could be rectified during the planning stage by developing budget and performance indicators to measure success.

Compromising or directive?

This relates to whether the occupational hygiene management program is acceptable to all parties or whether it is simply a directive of the management, occupational hygienist or risk manager. Ultimately, the decision to accept
a compromise between management and workers will reflect the parties’ own cultures and priorities.

**Step 4: Measurements and evaluation of performance**

Measuring progress and performance of occupational hygiene and risk management initiatives can be conducted in many ways. The outputs can be described as injury rates, environmental performance, health statistics and total financial losses. Whatever the output, performance should be checked against goals or standards. Such standards might include:

- legislation
- Australian standards
- industry standards or best-practice guidelines
- codes of practice or advisory-style standards
- occupational exposure standards.

This measurement can either be conducted internally or through the use of external consultants or auditors. Internal evaluations have the benefit of knowing the organisation’s systems intimately; however, it may be difficult to be objective, especially when attempting to be critical of systems and hazards that are encountered each day. This is where external consultants may provide a non-biased appraisal of the occupational hygiene and risk management system. They may also provide an alternative perspective and additional skills and knowledge of the hazards.

**Step 5: Review and improvement**

The review of systems should be aligned with the organisation’s goals and objectives. It will incorporate Steps 1 to 4 in assessing:

- whether the system obtained management support
- whether the aims and objectives were measurable and achievable
- whether the system was user-friendly.

The ultimate aim should be for continual improvement — even if, after an initial review is conducted, nonconformances or deficiencies are identified in the system. This is the building block for future improvement. Once the review has been completed, it is important to document the findings and keep records. This will be used for future reviews of performance and improvements.

**SUMMARY**

Managing occupational hygiene risks should use a systematic approach that incorporates the principles of risk management into an organisation’s management system. While there are many theories about management, a systematic approach to problems and issues can enhance communication and conditions in the workplace.
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