



Chemical Hazards

Core Body of Knowledge for the
Generalist OHS Professional



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Chemical Hazards

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Abstract

Chemical hazards are a major occupational health and safety issue in Australian workplaces. Management of chemical hazards requires the combined efforts of Occupational Health and Safety (OHS) specialists, including generalist OHS professionals, occupational hygienists and occupational health practitioners. This chapter presents basic chemical hazard knowledge required by the generalist OHS professional. After brief consideration of the historical context of chemical reactivity and toxicity issues, the chapter addresses acute and chronic exposure, chemical hazard classification systems, and the identification, risk assessment and control of chemical hazards. Emphasis is placed on the importance of working with a range of OHS specialists to ensure a range of skills is directed at preventing fatality, injury, disease and ill health arising from this complex area of occupational health and safety.

Keywords

hazardous chemical, hazardous substance, dangerous goods, globally harmonised system, occupational hygiene, occupational exposure standard, monitoring

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1 Introduction

The Australian *National OHS Strategy 2002–2012* included “prevent occupational disease more effectively” as one of five national priorities (NOHSC, 2002, p. 5). Of eight identified categories of occupational disease, three are associated with chemical hazards – cancer, respiratory disease and contact dermatitis (NOHSC, 2002). From 2000–01 to 2006–07, a decreasing trend was observed for contact dermatitis; however, there was no clear increase or decrease evident in the rates of respiratory disease or occupational cancers (Safe Work Australia, 2010a). Thus chemical hazards remain a major occupational health and safety (OHS) issue in Australian workplaces.

While chemical hazards are often associated with Major Hazard Facilities¹ and chemical transport, they are ubiquitous in workplaces and so are within the scope of practice of all generalist OHS professionals (see, for example, OSHA, 2004). The modern approach to chemical hazard control encompasses both the reactivity² and toxicity of chemicals. Because the management of the transport, storage and handling of bulk chemicals or explosives is generally outside the scope of the generalist OHS professional role, this chapter focuses primarily on the toxicity of chemicals. However, the principles discussed also apply to chemical reactivity.³

This chapter includes a brief review of the history of chemical hazard management and considers the extent of the problems posed by chemical hazards. In addressing the knowledge required to understand chemical hazards and control measures, the chapter distinguishes between acute and chronic exposures, discusses chemical classification systems, and applies a risk-management framework to consider issues related to identification of chemical hazards, risk assessment and control. After outlining the current legislative framework as it relates to hazardous chemicals, the chapter concludes with a discussion of the implications for OHS practice. It is assumed that the generalist OHS professional has sufficient knowledge of chemical states, structure and reactivity, and of the biological systems of the human body, to understand how chemical hazards behave and how they cause damage.⁴

1.1 Definitions

A **chemical** is “any element, chemical compound, or mixture of elements and/or compounds:”

¹ “Major Hazard Facilities (MHF) are locations such as oil refineries, chemical plants and large fuel and chemical storage sites where large quantities of hazardous materials are stored, handled or processed” (Safe Work Australia, 2012).

² “Reactivity is the tendency of a material or combination of materials to undergo chemical change under the right conditions” (CCPS, 2001, p. 2).

³ For more information on process safety see, for example, AICHE, 2010; Crowl & Louvar, 2011.

⁴ See *OHS BoK Foundation Science* and *OHS BoK The Human: As a Biological System*

- **Element** – the simplest form of matter that cannot be broken down further by chemical means. There are currently 109 known elements in the periodic table. Examples of elements are aluminium, carbon, chlorine, hydrogen, mercury and oxygen.
- **Chemical compound** – a substance consisting of two or more elements combined or bonded together so that its constituent elements are always present in the same proportions.
- **Mixture** – any combination of two or more chemicals if the combination is not, in whole or in part, the result of a chemical reaction. (OSHA, 2007)

While there is a prescribed process for classifying chemicals as hazardous substances (NOHSC, 2004), **hazardous substances** may be operationally defined as “those that, following worker exposure, can have an adverse effect on health” (Safe Work Australia, 2010b). **Dangerous goods** are “substances, mixtures or articles that, because of their physical, chemical (physicochemical) or acute toxicity properties, present an immediate hazard to people, property or the environment” (Safe Work Australia, 2010b) and are prescribed as such by a competent authority (NTC, 2007). The term **hazardous material** has a broader definition, and is used by emergency agencies to refer to materials that are to be treated as hazardous. The more recent term, **hazardous chemical** refers to substances that fall into the internationally agreed *Globally Harmonized System of Classification and Labelling of Chemicals* (GHS) (UN, 2011) for health effects, physicochemical properties or environmental impacts, or otherwise meet the criteria for inclusion on the list of hazardous chemicals. In practice, the term combines attributes of dangerous goods and hazardous substances, and will become the all-encompassing term after full implementation of the GHS in Australia in 2016 (Safe Work Australia, 2012).

Applying the energy-based classification of hazards,⁵ **chemical hazards** may be defined as those where the potentially hazardous energy is released through disruption of the molecular bonding as a result of chemical reaction (usually a reactive chemical hazard). In contrast, toxic chemicals are defined based on their effect; for example, the National Transport Commission defined toxic chemicals as “substances liable either to cause death or serious injury or to harm human health if swallowed or inhaled or by skin contact” (NTC, 2011, s 2.6.1). For the purposes of this chapter, hazardous chemicals include industrial chemicals, pesticides, agricultural chemicals, pharmaceuticals, cosmetics and food-related chemicals that may be present in the workplace and “that have an adverse effect on a worker’s health as a result of direct contact with or exposure to the chemical” (Safe Work Australia, 2012).

2 Historical context

While the use of hazardous chemicals in work processes predates recorded history (see, for example, Shakhshiri, 2003), industry became rapidly more complex and use of sophisticated chemicals became increasingly widespread in the 20th century (Fraser, 1996). Because it was recognised early that some substances are unstable by themselves or

⁵ See *OHS BoK Hazard as a Concept* (section 3.2, Table 1)

highly reactive in combination, and some substances are poisonous or narcotic, the history of chemical hazards may be considered in terms of these parallel streams of chemical safety (reactivity issues) and chemical hygiene (toxicity issues).

2.1 Chemical safety (reactivity issues)

Initially in the United Kingdom in the 19th century, military and industrial applications of chemicals led to the development of a chemical manufacturing sector. Because the storage, transport and handling of certain bulk chemicals were problematic, legislative control of dangerous goods evolved. The *Petroleum Act 1879* was enacted following a series of rail accidents involving chemicals, including the 1868 Abergele Rail disaster in which 33 people died when a train crashed into goods wagons containing paraffin oil that ignited (Hume, 2006). This Act was updated to become the *Petroleum (Consolidation) Act 1928* (Geo. 5), which was the major legislative control on the transport of dangerous substances in the UK until the 1980s (HSE, 2011).

Several chemical disasters, including incidents in Flixborough in the UK (1974), Beek in The Netherlands (1975) and Seveso in Italy (1976), provided the impetus for a European regulatory framework “known as the ‘Seveso’ Directive (82/501/EEC) [that] was aimed at the prevention of major accidents which might result from certain industrial activities and with the limitation of their consequences for man [*sic*] and the environment” (Vernon, 2005, p. 43). In 1987, this Directive was amended following “severe accidents at the Union Carbide factory at Bhopal, India, in 1984 where a leak of methyl isocyanate caused more than 2500 deaths and at the Sandoz warehouse in Basel, Switzerland, in 1986 where fire-fighting water contaminated with mercury, organophosphate pesticides and other chemicals caused massive pollution of the Rhine and the death of half a million fish” (EC, 2011). Further amendments occurred in 1988 “aimed at broadening the scope of the Directive, in particular to include the storage of dangerous substances” (EC, 2011). In 1996, ‘Seveso II’ increased emphasis on environmental protection and introduced new requirements “relating to safety management systems, emergency planning and land-use planning and a reinforcement of the provisions on inspections to be carried out by Member States” (EC, 2011). In 2003, Seveso II was revised in the aftermath of several industrial accidents⁶ and the results of research on carcinogens and environmental impacts “to cover risks arising from storage and processing activities in mining, from pyrotechnic and explosive substances and from the storage of ammonium nitrate and ammonium nitrate based fertilizers” (EC, 2011).

The series of disasters also led to the development and refinement of hazard analysis and risk-assessment techniques that have implications for OHS professionals. It is illustrative to reflect on the development of the hazard-identification technique Hazard and

⁶ Disasters in this period included incidents in Enschede, Holland (2000), Toulouse, France (2001), and Baia Mare, Romania (2001).

Operability (HAZOP) Study. When considering the design of a plant for the production of phenol and acetone in the 1960s, a team at the British company Imperial Chemical Industries (ICI) initially applied the established technique of *critical examination* to generate alternatives before turning their attention to searching for *deviations*. Further refinement saw this established as the third stage of a hazard-analysis procedure (after conceptual and specification stages) that gained considerable attention following the Flixborough disaster in 1974. Use of the technique was encouraged by the Chemical Industries Association's 1977 publication of *A Guide to Hazard and Operability Studies*. Subsequently, the multidisciplinary-team procedure was developed into a formal training program by the Institution of Chemical Engineers (ICHEME, 2008; Kletz, 1999)

2.2 Chemical hygiene (toxicity issues)

Through the ages people have been interested in toxic chemicals, primarily as medicines or as poisoning agents, but occasionally as issues of occupation.⁷ In the early 1500s, Swiss physician Philippus Paracelsus documented that specific chemicals were responsible for toxicity of poisons and that the human body's reaction to those chemicals was dose-dependent, and encouraged the use of experimental animals to study the toxic effects of chemicals (Borzelleca, 1999). However, it was the 19th century before the first structured research using experimental animals to explore the relationship between chemical exposure and toxic effect was undertaken. In Germany in 1883, Max Gruber published the results of experiments on hens and rabbits exposed to carbon monoxide; this work constituted the earliest documented effort directed at setting an occupational exposure limit (OEL) (Paustenbach, 1998; Paustenbach & Sahmel, 2011). Around the same time, Karl Lehmann and colleagues began an influential series of animal experiments geared to elucidating OELs for many chemical substances (Paustenbach & Sahmel, 2011).

The first list of standards for chemical exposures in industry – *Maximum Allowable Concentrations* (MACs) – were published in the early 1940s by the American Conference of Governmental Industrial Hygienists (ACGIH, 2010), heralding the need for measurement technologies. Since then, a variety of methods and exposure criteria have been developed, including the widely accepted ACGIH's Threshold Limit Values (TLVs) (ACGIH, 2008; Paustenbach & Sahmel, 2011). These developments have been accompanied by increasing acknowledgement of the importance of occupational physicians and toxicologists in recognising diseases related to workplace chemical exposures.

⁷ See *OHS BoK The Human: As a Biological System* (section 2)

2.3 Globally harmonised system of classification and labelling

The involvement of international organisations in the development of recommendations for management of chemical hazards commenced in the 1950s (ILO, 1999):

In 1952, the International Labour Organization (ILO) called on its Chemical Industries Committee to study the classification and labelling of dangerous substances. In 1953, the United Nations Committee of Experts on the Transport of Dangerous Goods (UN CETDG)...elaborated the first internationally recognized classification and labelling system for the purpose of transporting dangerous goods. It was first published in 1956 as the UN Recommendations on the Transport of Dangerous Goods (UN RTDG) [and is] now included in the transport legislation of most of the UN member States and also used for labelling chemicals in the workplace in a large number of developing countries (ILO, 1999).

In 1989 the ILO adopted:

...a Resolution concerning the harmonization of systems of classification and labelling for the use of hazardous chemicals at work, and in 1990, a Convention (No.170) and a Recommendation (No.177) concerning safety in the use of chemicals at work (ILO, 1999).

In 1992, a Coordinating Group for the Harmonization of Chemical Classification Systems was established and, with the support of an international mandate, the UN Conference on Environment and Development (UNCED) endorsed:

A globally harmonized hazard classification and compatible labelling system, including material safety data sheets and easily understandable symbols, should be available, if feasible, by the year 2000 (UN, 2011, p. iii).

After approval by a UN Committee of Experts, the first version of the system was published in 2003; since then, it has been updated every two years (UN, 2011). In Australia, introduction of the Globally Harmonised System (GHS) will come into effect with the adoption of the national Model Work Health and Safety legislation in 2012; however, there will be a five-year transition period during which either the GHS or the NOHSC classification systems may be used (Safe Work Australia, 2010c).

3 Extent of the problem

As observed by the ILO in 1996, chemicals are part of life and increasingly unavoidable:

There are five to seven million different chemicals in the world. At least 400 million tonnes of chemicals are produced worldwide each year...In North America alone at least 1,200 **new** chemicals are developed each year. The frightening reality is that, for the vast majority of the chemicals used and being developed, little or nothing is known about their possible immediate or long-term effects on the health of the workers who produce them or use them at work. Yet workers continue to be required to work with potentially toxic substances. (ILO, 1996)

Just as there are many different hazardous chemicals in different workplaces, exposure to these substances in the workplace can lead to a wide variety of short-term and long-term health effects. In a systematic review by the World Health Organization, it was

conservatively estimated that “4.9 million deaths (8.3% of total deaths) and 86 million Disability-Adjusted Life Years (DALYs) (5.7% of total disease burden) were attributable to environmental exposure and management of selected chemicals in 2004” (Prüss-Ustün, Vickers, Haefliger & Bertollini, 2011, p. 1).

National workers’ compensation claims data (Safe Work Australia, 2006-7 for the year 2006–07⁸ report 1350 claims for chemical exposures (1.0% of all claims); of these 880 were for single-contact exposures, 400 for long-term contact and 70 were not classified as to type of exposure. 23% of claims for a single exposure to chemicals involved more than 6 weeks lost work time while 30% of claims for long term exposure were for more than 6 weeks lost work time. Three fatalities were recorded for a single contact with chemicals plus 58 fatalities associated with long term contact with chemicals with a further 2 fatalities not being classified as to type of exposure. In total 20% of all fatalities were attributed to chemical exposure. 41% of recorded claims arising from a single contact were burns and 22% were for skin/dermatitis conditions while 41% of claims for long term contact were associated with respiratory conditions and 28% skin/dermatitis conditions. The industries with the highest number of claims for chemical exposure were Manufacturing with 31% and Construction with 11% of chemical-related claims.

While these figures are of concern they significantly under-estimate the impact of chemical hazards as the effects of exposures to some chemicals may not manifest for decades and employee turnover results in underreporting of exposures (Collins & Schneid, 2001). A more realistic estimate may be that provided by Morrell, Kerr, Driscoll, Taylor, Salkeld & Corbett (1998) in their 1996 report which estimated that 2290 people died annually in Australia as a result of occupational exposure to hazardous substances; of these, only 30–40 were from acute poisoning with the majority due to diseases of long latency. The prime cause of death was cancer, followed by renal, cardiovascular, neurological and chronic respiratory disease. The authors concluded:

The finding of an appreciable burden of mortality that is attributable to past occupational exposure to hazardous substances emphasises the necessity for occupational health and safety authorities to measure and reduce worksite exposures” (Morrell et al., 1998, p. 634).

While fragmented, occupational health research is evaluating health risks that exist for many chemicals. For example, as noted by Snedeker (2006), much of our knowledge of associations between chemicals and breast cancer risk emanates from occupational cancer literature. Additionally, international asthma research has indicated that:

...9–15% of cases of asthma in adults of working age are either caused or aggravated by occupational factors [primarily] various chemicals used in paints, manufacturing and cleaning products, latex gloves, animals and dusts from grain, flour and wood. These agents pose most risk for people employed in the plastics, rubber and chemical industries, nurses, timber workers and welders, and jobs involving painting (particularly spray painting), dyeing, cleaning, baking and food

⁸ This was the most up-to-date complete data available at the time of writing.

processing, farming, laboratory work and working with animals. (Nicholsen et al. as cited in ACAM, 2008, p. 145)

4 Understanding chemical hazards and risks

To fully comprehend chemical hazards and risks in the workplace, a generalist OHS professional requires knowledge of the toxic and physicochemical attributes of the chemical (the hazard), paired with an understanding of the potential for worker exposure to the chemical or its impacts. This understanding must include factors related to acute and chronic exposure, chemical hazard classification systems, and chemical hazard identification, risk assessment and risk communication.

4.1 Acute and chronic exposure

Acute toxicity, which refers to “the adverse health effects following a single or limited number of exposures” (Robinson & Thorn, 2005, p. 3) can occur as a result of exposure due to equipment failure, inadequate protection during maintenance or cleaning, or improper handling of a chemical. Although the effects of acute exposures are usually obvious within a short period, the effects of exposure to some chemicals such as pesticides may not appear for several days. Temporary effects of acute chemical exposure may include skin irritation, headache and nausea while permanent effects include scars from acid burns.

Chronic toxicity refers to “the adverse health effects resulting from continuous or intermittent exposure” (Robinson & Thorn, 2005, p. 3) over a prolonged period, often to relatively low levels of chemical. There may be a latency period of many years before the effects of chronic exposure to a chemical are expressed. For example, the long-term impact of chronic exposure to toxic chemicals on Royal Australian Air Force personnel who undertook maintenance of F-111 aircraft fuel tanks over a period of 27 years is well documented (see Hopkins, 2005; RAAF, 2001). Some cancers are considered to be related to exposure to workplace chemicals; for example, mesothelioma is a typically fatal cancer that occurs in some people exposed to asbestos (see, for example, Mesothelioma Centre, 2012).

Knowledge of the impact of chronic exposure to chemicals is incomplete, a situation that can be compounded by the delay before symptoms are expressed.

Current theories on cancer suggest that its cause is a multi-step process arising from a combination of factors that vary by nature and degree of exposure to carcinogens over time, mediated by individual behaviour, as well as genetic factors. There are a number of known carcinogens, however the specific toxicity, potency and latency periods associated with many agents are unknown. Further, given the long latency period associated with many carcinogenic exposures, workplace exposures and the onset of a specific cancer may not be readily associated. (Safe Work Australia, 2010a, p. 15)

4.2 Chemical hazard classification systems

There is a high potential for confusion in identifying chemicals. Chemical nomenclature is very precise with each chemical having a unique identifying name assigned by the International Union of Pure and Applied Chemistry (IUPAC) and a unique identifying number assigned by the Chemical Abstracts Service (CAS) (see AMC, 2011). However, it is often the case that more than one molecular structure exists for a given molecular formula (e.g. $C_6H_{12}O_6$ can describe glucose or fructose or a number of other substances). In addition, a chemical product is usually made up of several chemicals. Product names can be very similar and different manufacturers can have different names for the same materials. For example, dry cleaning fluid as a pure chemical may have a unique IUPAC systematic name (e.g. tetrachloroethene) and a corresponding unique CAS number (e.g. 127-18-4); also, it may be known by its common name (perchloroethylene), manufacturer's product name (e.g. PerSec), trade name (e.g. perc) or abbreviation (PCE). In addition, chemical hazard information may be conveyed under the generic grouping to which the chemical belongs; in this case, chlorinated solvents. To fully understand a chemical hazard, it may be necessary to search for information under all relevant names.

While it does not obviate the need to understand the variety of chemical classification options, the GHS (see section 2.3), provides an internationally “uniform way of classifying chemicals, as well as informing chemical users about chemical hazards they may be exposed to” (ASCC, 2006, p. 1). The GHS covers all hazardous chemical substances, solutions and mixtures of chemicals with the classifications linked to hazard symbols, signal words, hazard and precautionary statements (similar to current risk and safety phrases used in labelling hazardous chemicals), which provide information on safe storage, handling, disposal, personal protection and first aid (see Safe Work Australia, 2010c).

Safe Work Australia is the lead agency for promoting implementation of the GHS in Australia, and has developed a new framework for the control of workplace hazardous chemicals that utilises the GHS as the primary hazard classification and hazard communication system.⁹

4.3 Identifying chemical hazards

4.3.1 Chemical label

Current labelling requirements in Australia vary according to the intended use of the material and is based on the classification of chemicals in accordance with the requirements of the *Australian Code for the Transport of Dangerous Goods by Road & Rail* (NTC, 2011) and / or the *Standard for the Uniform Scheduling of Drugs and*

⁹ For more information about the GHS in Australia see Safe Work Australia, 2010c.

Poisons(TGA, 2007).¹⁰. Introduction of the GHS, along with the national *Model Work Health and Safety Regulations* (Safe Work Australia, 2010d), provides a consistent approach to classifying and labelling all dangerous goods, hazardous substances and poisons. The manufacturer or importer is responsible for ensuring that any chemical or chemical product is classified and labelled according to current regulatory requirements (Safe Work Australia, 2011a).

From the perspective of the OHS professional and the workplace user of the chemical, the important label components under the GHS are signal words, hazard statements, precautionary statements and pictograms.

Signal words are used to indicate the relative level of severity of a hazard. The GHS uses ‘Danger’ and ‘Warning’ as signal words. ‘Danger’ is used for a more severe or significant hazard, while ‘Warning’ is used for the less severe hazards...

Hazard statements describe the nature of a hazard, including the degree of hazard, where appropriate. A unique hazard statement is assigned to each hazard class and category...

Precautionary statements describe the recommended measures that should be taken to minimise or prevent adverse effects resulting from exposure to, or improper storage or handling of, a hazardous chemical. Precautionary statements are assigned to each hazard class and category.

Precautionary statements are separated into five categories:

- Prevention statements refer to precautions to be taken to prevent an accident or exposure.
- Response statements refer to instructions in case of an accident.
- Storage statements refer to instructions for safe storage of the chemical.
- Disposal statements refer to appropriate disposal instructions.
- General statements for use as appropriate. (Safe Work Australia, 2011a, p. 11)

The GHS specifies nine hazard pictograms relating to physical, health and environmental hazards (Safe Work Australia, 2011a) (Figure 1). Where appropriate, “class labels recommended for the transport of dangerous goods as specified in the ADG Code may be used instead of the relevant hazard pictograms specified in the GHS” (Safe Work Australia, 2011a, p. 12).

¹⁰ Poisons are separately defined in Australian State legislation under the Standard for the Uniform Scheduling of Drugs (or Medicines, depending on the state) and Poisons (SUSDP or SUSMP) produced by the National Drugs and Poisons Scheduling Committee (NDPSC), a committee of the Therapeutic Goods Administration (TGA).

<u>Pictogram</u>	<u>Hazard</u>	<u>Pictogram</u>	<u>Hazard</u>
 Exploding bomb	- Explosive	 Gas cylinder	- Gases under pressure
 Flame	- Flammability	 Corrosion	- Corrosive
 Flame over circle	- Oxidising	 Skull and crossbones	- Acute toxicity
 Health hazard	- Chronic health hazards	 Exclamation mark	- Certain health hazards (e.g. sensitisers)
 Environment	- Environmental hazard		

Figure 1: GHS pictograms (Safe Work Australia, 2011a, p. 89)

4.3.2 Safety data sheet

As explained by Safe Work Australia (2011b, p. 5):

A Safety Data Sheet (SDS), previously called a Material Safety Data Sheet (MSDS), is a document that provides information on the properties of hazardous chemicals and how they affect health and safety in the workplace. For example it includes information on the identity, health and physicochemical hazards, safe handling and storage, emergency procedures and disposal considerations.

An SDS is an important tool for eliminating or minimising the risks associated with the use of hazardous chemicals in workplaces.

The manufacturer or importer is required by legislation to prepare an SDS where the substance, mixture or article is classified as a hazardous chemical or “for any chemical that may adversely impact the health or safety of persons or the environment, but has insufficient information to allow it to be correctly classified” (Safe Work Australia, 2011b, p. 7).¹¹ The SDS must address specified criteria for content and layout (see Safe Work Australia, 2011b).

While SDSs should be the initial source of information on chemical hazards, they are not the only source and they have several limitations:

- Repeated or long-term use of a chemical requires information on chronic health effects. Some SDSs may only provide data based on short-term animal studies or simply state that there is no information on long-term effects.
- The SDS is meant to describe the hazard for the product as a whole; however, if a chemical mixture is not tested, the SDS may only provide hazard information pertaining to selected ingredients.
- Where there is a mixture of chemicals, most SDSs combine all the hazards from all components of the mixture; this may result in understating the risk if there are synergistic effects as a result of interaction between components. Similarly, the SDS will not address possible synergistic effects with other chemicals to which the worker may be exposed.
- Because chemical suppliers may not be aware of all possible applications of their chemical(s), precautions for use cited in the SDS may not be appropriate for all situations.

4.3.3 Hazardous chemical databases

Detailed information on hazardous chemicals is available from databases such as the *National Industrial Chemicals Notification and Assessment Scheme* (NICNAS) and the *Hazardous Substance Information System* (HSIS).

Located in the Australian Government Department of Health and Ageing, NICNAS:

- Provides a national notification and assessment scheme to protect the health of the public, workers and the environment from the harmful effect of industrial chemicals; and
- Assesses all chemicals new to Australia and assesses those chemicals already used (existing chemicals) on a priority basis, in response to concerns about their safety on health and environmental grounds (NICNAS, 2012).

Safe Work Australia (2011c) maintains the HSIS, a searchable database similar to the *European Substance Information System* (see ESIS, 2011). The HSIS provides information

¹¹ Refer to Safe Work Australia (2011b) for exceptions

on chemical name(s) and number, labelling requirements, concentration cut-offs for mixtures, hazard type, exposure levels and carcinogenic category, and lists any notices.

4.4 Risk assessment

In its most simplistic application, chemical risk assessment involves knowledge of how much of a particular substance constitutes a hazard and whether there is potential for worker exposure to that chemical to exceed the acceptable level. Where there is evidence of worker exposure to a hazardous chemical or release of such a chemical into the atmosphere and the controls are known, the OHS professional may go straight to controlling the exposure. However, there are situations when this simplistic approach is not appropriate. Chemical risk assessment is about more than assigning a rating, as in severity and likelihood tables, or comparing a measured exposure level with an exposure standard. The risk of harm or damage from chemical exposure is multifactorial, and is a function of the chemical state, the route of exposure, the dose-response relationship, the extent of exposure, the nature of the task or activity involving the chemical, the workplace environment and the individual worker. The sources of information for hazard identification discussed above (i.e. labels, SDS and hazardous chemical databases) also provide information for risk assessment. However, caution and some underpinning knowledge are required when applying information from such sources for risk assessment.¹²

4.4.1 Chemical state

While chemical hazard identification is about recognising the chemical as a potential source of harm, assessing the risk requires knowledge of how the chemical behaves and how it might cause harm.¹³ The state in which the chemical is being used (eg: solid, liquid or gas) is one factor that can impact on the level of risk. For example, in the case of most dusts, the finer the dust, the more toxic and reactive it is, and the more likely it is to remain airborne and penetrate the lungs. In such cases pelletised forms of the chemical have a lower risk than fine dusts.

4.4.2 Routes of exposure

For many chemicals, the level of risk is contingent on the route of exposure. Hazardous chemicals can enter the body through the respiratory tract via inhalation, through the skin via dermal contact and through the digestive tract via ingestion, or via injection directly into the bloodstream. Generally, it is thought that inhalation exposure is the most important

¹² For more detailed information than is provided in this section see, for example, van Leeuwen & Vermeire, 2007.

¹³ See *OHS BoK Foundation Science* and *OHS BoK The Human: As a Biological System*

route of exposure for risk assessment. However, some chemicals (e.g. pesticides) can be efficiently absorbed through the skin, chemicals can be ingested (e.g. by workers eating or smoking with contaminated hands), and injection can occur as a result of, for example, needle-stick injuries in medical science laboratories. Consequently, although exposure standards tend to focus on inhalation exposures, it is important for the OHS professional to be mindful of other potential exposure routes.

4.4.3 Dose-response

Dose-response, or the amount of the material likely to cause problems, is an important element in chemical risk assessment. Increasing doses of toxic chemicals will usually cause increasing severity of health effects. With explosive, reactive or flammable chemicals, there is often a concentration range in which a property emerges (e.g. flash point). However, use of the GHS effectively removes the need to consider the dose-response relationship as part of chemical risk assessment as it uses dose-response data to determine the classification of the chemical. For example, a chemical product containing acetone at concentrations greater than 20% is classified as a hazardous material and must be labelled 'F, Xi' or 'Flammable, Irritant;' at concentrations below 20%, only the 'F' signal word applies because the product is not construed as a hazardous material from an irritant viewpoint, but is still flammable at concentrations greater than 8%.¹⁴

4.4.4 Extent of exposure

Intensity, frequency and duration of exposure will affect the risk of harm. Exposure to a chemical may be assessed in one or more of three ways: inspection and observation, incident and first aid reports, and exposure monitoring.

Inspection and observation

'Walk-through' inspections, formal workplace inspections, and observation of work tasks can provide information on the risk associated with use of chemicals. At the most basic level, visible contamination, spills and storage issues may indicate the potential for inhalation, skin contact, or hazardous interactions such as contact between flammable materials and sources of ignition. Also, inspections and maintenance records can provide relevant information on adequacy of controls such as ventilation (Safe Work Australia, 2011d).

While an odour may indicate the presence of a chemical in the air there are many examples where odour is not a good indicator of risk. Some chemicals are readily smelled at levels before they are considered toxic (e.g. ammonia); however, other chemicals have poor warning properties, in that they are toxic before the odour is noticeable (e.g. carbon

¹⁴ For more information on dose-response see, for example, IPCS, 2009.

monoxide). Furthermore, other chemicals can cause olfactory fatigue where the warning properties are not recognised at higher concentrations and death can result (e.g. hydrogen sulphide). In some cases, odour may lead to psychosomatic responses (e.g. where the smell of a chemical can induce nausea, but is not necessarily toxic).

Incident and first aid reports

Reports of incidents (e.g. fires or spills) and complaints of health effects (e.g. skin irritation or breathing difficulties) provide information vital for chemical hazard identification. Also, they are key sources of information about the level of risk and the adequacy and effectiveness of controls.

Exposure monitoring

Where there is evidence of worker exposure to toxic chemicals or release of such chemicals into the atmosphere, the OHS professional may proceed to immediate control of the exposure, or may elect to determine the extent of exposure using **monitoring instrumentation**. There are several simple devices for assessing ambient air contamination, such as the short-term detector tube and hand-held pump (e.g. Dräger detector tube and pump). The variety of tubes available for monitoring air contaminants, mostly gases and vapours, are generally used to measure instantaneous or peak air concentrations of contaminants. Monitoring requires an understanding of sampling requirements to address all possible exposure across the ‘lifecycle’ of the task, including maintenance and cleaning. While it is appropriate for the suitably qualified and experienced generalist OHS professional to carry out basic monitoring, more sophisticated monitoring and the interpretation of results requires specialist occupational hygiene knowledge.

For health hazards, measurements of chemical concentrations in workplace air are compared to **Occupational Exposure Standards (OESs)**. There are three types of exposure standard:

Peak limitation means a maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.

Short term exposure limit (STEL) means the airborne concentration of a particular substance calculated as a time-weighted average over 15 minutes.

8-hour Time-weighted average (TWA) means the average airborne concentration of a particular substance when calculated over an eight-hour working day, for a five-day working week. (Safe Work Australia, 2011e, p. 6)

OESs in use in Australia are published by Safe Work Australia (see Safe Work Australia, 2011c,e). Not all chemicals have exposure standards and some have more than one, depending on whether the chemical has both short-term and long-term health effects. Australian exposure standards should be used where available; if there is no applicable

Australian standard, an international standard may be applied under the guidance of an occupational hygienist or occupational physician.¹⁵

Simply comparing a measured concentration of a chemical in the workplace to its exposure limit, and finding it below the OES cannot be interpreted as an absolute indicator of 'safe' condition. Cowley (2011) cautioned that exposure should always be maintained as far below the OES as possible.

Occupational Exposure Standards do not represent fine lines between what is safe and what is dangerous to health because:

- they change as new information becomes available about the toxicity of chemicals
- individuals vary in response to chemical exposure;
- they do not account for absorption of chemicals by routes other than inhalation;
- they do not account for exposures to mixtures of chemicals that may have synergistic effects in the body; and
- they are often based on the results of experiments on animals, requiring extrapolation to humans or epidemiological studies requiring some reliance upon historical data (Cowley, 2011, pp. 84–85).

Other limitations of OESs include:

- They were established to protect the majority of workers over their working lifetime therefore do not necessarily protect all workers at all times.
- While some are based on instantaneous peaks or short-term measures (15 minutes), the majority are 8-hour averages and adjustment may be required if workers are engaged in extended shifts or if exposure times vary.
- Some exposure standards specify size-selective sampling (e.g. for fine dust), but essentially all of the standards refer to personal sampling, rather than sampling in a fixed location.
- While some OESs may have a 'skin' notation indicating that an appreciable amount of exposure may occur through the skin, OESs refer to concentrations in the workplace air, and do not apply for skin absorption or ingestion of chemicals. Therefore where there is a suspicion of skin exposure or ingestion, biological monitoring for exposure may be necessary. In some cases, wiping of skin or work surfaces may be used to indicate absorption of certain chemicals (see Ness, 1994).

For more information about OESs see, for example, Grayson (2007).

¹⁵ The TLVs (Threshold Limit Values) are similar to the OELs, but they refer to exposure criteria promulgated by the American Conference of Governmental Industrial Hygienists (ACGIH), and are technically not applicable in Australia.

Biological and health monitoring

Biological monitoring – “the measurement and evaluation of hazardous substances or their metabolites in the body tissues, fluids or exhaled air of an exposed person” (Safe Work Australia, 2011f) (WHSR s 1.1.5) – may detect the presence of chemicals in the body before any signs or symptoms of disease are expressed. Biological monitoring is conducted as part of health surveillance programs.

The national Model Work Health and Safety Regulations (Safe Work Australia, 2010d) define health surveillance as “monitoring the person to identify changes in the person’s health status because of exposure to hazardous chemicals” (WHSR s 1.1.5). The regulations specify that health surveillance must be carried out when there is exposure to certain specified chemicals and by registered medical practitioners with relevant competencies.¹⁶

Both types of monitoring are important in providing an assessment of exposure by all routes (inhalation, skin etc) and the efficacy of control measures that are designed to avoid exposure.

4.4.5 Task or activity

Aspects of a work task or activity may impact on the level of exposure and therefore risk. For example, in agricultural situations generally there will be a higher risk of chemical exposure associated with use of a spray application for a pesticide than a brush-on application. Exposure to two or more chemicals creates the potential for them to react ‘synergistically;’ that is, the health impacts of the two chemicals together are greater than that of the individual chemicals alone. The Canadian Centre for Occupational Health and Safety (CCOHS, 2004) explained that synergism can occur when a chemical either inhibits or accelerates an enzyme function to cause a greater biological impact, and provided the following examples:

- (a) Carbon tetrachloride and ethanol (ethyl alcohol) are individually toxic to the liver, but together they produce much more liver injury than the sum of their individual effects on the liver.
- (b) The much higher incidence of lung cancer resulting from occupational exposure to asbestos in smokers (compared to exposed non-smokers).

Other types of chemical interaction include antagonism and potentiation:

Antagonism – Antagonism is the opposite of synergism. It is the situation where the combined effect of two or more compounds is less toxic than the individual effects...

Potentiation – This effect results when one substance that does not normally have a toxic effect is added to another chemical, it makes the second chemical much more toxic... (CCOHS, 2004)

¹⁶ For more information on biological monitoring as part of health surveillance see, for example, DCEP, 2008; Edwards, 2007.

As these locally specific task and activity aspects cannot be adequately addressed in SDS information, knowledge of the specific circumstances must be considered in the risk assessment. This may require specialist input.

4.4.6 Workplace environment

A range of factors in the workplace environment may impact on exposure to a chemical. These factors may vary with the season, maintenance periods or other activities in the area, and may include:

- Environmental conditions such as temperature, sunlight and humidity
- Sources of ignition
- Potential interaction with nearby processes or incompatible chemicals.

4.4.7 Worker

A worker's exposure to a chemical may vary depending on their role in the task or activity, their training and skills, and their use of personal protective equipment (PPE). Also, individual susceptibility is influenced by factors such as smoking, alcohol consumption, pregnancy, use of medications and drugs, general health status and genetic factors. An individual's status in terms of these factors may not be readily apparent, but may be discerned by an occupational health practitioner.¹⁷

4.5 Risk communication

Communication with workers, supervisors and managers about chemical hazards, potential and actual exposures, and the need for monitoring is essential. Exposure monitoring data should be shared with those potentially exposed and those involved in the monitoring. While individual results of biological monitoring and health surveillance are confidential and therefore should only be shared with the individual, summarised results should be communicated to those involved in making decisions about risk.

In communicating information about the risk of chemical hazards, the purposes of ambient monitoring and biological monitoring, the limitations and uncertainties associated with the data, and the implications of the exposure should be explained. As most workers will be able to privately access information (e.g. via the Internet), it is important that the information supplied is from authoritative sources, technically correct, and communicated in a clear and unambiguous manner while taking account of possible sensitivities.

¹⁷ For more information on chemical health risk assessment see NOHSC, 1994.

5 Legislation and standards

The management of chemicals is subject to a complex regulatory regime of Commonwealth and state legislation, which includes notification of new or imported chemicals, explosives, dangerous goods in transport, poisons/pharmaceuticals, narcotics, agricultural chemicals, hazardous chemicals in the workplace, hazardous waste and chemicals hazardous to the environment. The SDS should contain reference to the appropriate regulations impacting on the management of specific chemicals in the workplace. This section focuses on the obligations under the national model work health and safety legislation.

The national *Model Work Health and Safety Act* (WHS Act ss 22–25) (Safe Work Australia, 2011f) and the *Model Work Health and Safety Regulations* (Safe Work Australia, 2010d) place extensive obligations on persons who design, manufacture, import or supply chemicals that are used or could be used in the workplace. Depending on the particular role, the responsibilities include ensuring so far as is practicable that:

- The chemical is designed, manufactured and supplied so as to be without risk to the health and safety of persons
- Necessary calculations, analysis, testing or examination are carried out
- Adequate information is provided to appropriate persons.

The scope of the obligations cover those who:

- Use or handle the chemical for the purpose for which it is intended
- Carry out any reasonably foreseeable activity at the workplace in relation to manufacture or use of the chemical
- Store the chemical
- Dispose of the chemical
- Are at or in the vicinity of the workplace where the chemical is used.

These obligations are in addition to the primary duty of care on a person conducting a business or undertaking (PCBU) that requires, so far as is reasonably practicable, the health and safety of persons engaged in work influenced or directed by the person or who are at the workplace (WHS Act s 19).

In addition to providing detail on the general obligations of designers, manufacturers, importers and suppliers regarding chemical classification, packing, labelling and Safety Data Sheets, the regulations place the following obligations on PCBUs:

- Labelling of chemical containers

- Providing access to Safety Data Sheets
- Development and availability of a hazardous chemicals register
- Requirements relating to hazardous chemicals (Dangerous Goods) (WHSR s 7.1).

6 Control of chemical hazards

As with all risk-management activities, the major components of control are development and implementation of controls, and the ongoing monitoring of their effectiveness.

6.1 Priorities for control action

Chemical hazard control aligns well with the hierarchy of control. However, unless the hazardous chemical is eliminated, a ‘package’ of controls will be required to minimise the residual risk and to implement a strong sequence of barriers and defences to ensure that the controls remain effective.¹⁸ The hierarchy of control as it applies to toxic chemicals is described below.¹⁹

Elimination

The most effective and reliable controls are those that result in elimination of the hazardous chemical.

Substitution

Substitution of a hazardous chemical for a less hazardous one is the next control of choice; however, care must be taken to ensure that the substituted chemical does not introduce new hazards. Substitution also may involve using the chemical in a less hazardous form or process (e.g. use of chemical in a pellet form rather than a dust).

Isolation

Isolation of the chemical in time or space from those potentially exposed can be an effective means of control (e.g. locating people in a protected control room, installing a buffer area around a chemical reactor, using the material when people are not in the vicinity).

Engineering controls

Engineering controls typically reduce exposure at the source (e.g. by enclosing the process in vessels or pipes, or by local exhaust ventilation). Prevention of uncontrolled releases is important; this may be achieved using strategies such as quantity reduction, segregation,

¹⁸ See *OHS BoK Control*

¹⁹ While the hierarchy of control applies to toxic and reactive chemicals, there is the added requirement of controlling the potential hazards associated with responding to chemical emergencies, such as spills and fires or when monitoring data shows excessive exposure. While information on control is usually included on a SDS, this generic information must be interpreted to develop actions specific to the situation.

secure storage and temperature control. The ongoing integrity of engineering controls usually requires introduction of administrative controls such as maintenance.

Administrative controls

Generally, administrative controls will be required to supplement higher-level controls. Administrative controls may include maintenance of equipment and training of workers and their managers in the operation of the equipment. Preventative maintenance is important in preventing uncontrolled releases. Work procedures may need to be developed to ensure that engineering controls function as designed; this includes any safe-handling procedures and special storage instructions.

Personal protective equipment

Any residual risk may require workers to wear personal protective equipment (PPE) to reduce exposure to chemicals absorbed through respiration or skin or eye contact. Specialist knowledge may be required to ensure selection of the correct type of PPE for a specific chemical.

Selection of gloves for protection against chemicals absorbed through the skin requires reference to chemical resistance charts or databases and consideration of the potential for chemical permeation, penetration and degradation of the PPE. In some situations, chemically resistant safety footwear is required. Inappropriate or poorly maintained PPE itself can act as a source of chemical exposure (e.g. contaminated gloves can be a source of ongoing exposure through persistent permeation or occlusion of the chemical inside the gloves).

While it would be expected that the risk associated with tasks such as decanting of chemicals would be controlled through enclosure or other engineering controls, some chemical-handling tasks may require eye protection. Depending on the task, this may be safety goggles or full-face protection.

There is a wide range of PPE for respiratory protection. While Australian Standards provide information on appropriate selection of respirators, the interpretation of these Standards and the selection of the appropriate respiratory protection require specialist knowledge. Fitting, maintenance and user training is important for all types of PPE, but especially for respiratory protection.

For more information on chemical hazard control see, for example, CCOHS (2006) and Safe Work Australia (2011d).

6.2 Evaluation of effectiveness of control

Once implemented, the effectiveness of the controls should be evaluated. Information on the effectiveness of controls may be collected in several ways:

- Routine ambient air monitoring to determine whether air concentrations are maintained below the recommended limits
- Walk-through surveys to observe correct handling of materials and use of engineering, administrative and PPE controls
- Reporting and investigation of spills, losses of containment, environmental releases or OESs being exceeded
- Biological monitoring of urine, blood, exhaled breath, hair or saliva samples from potentially exposed individuals
- Medical surveillance, including monitoring the exposed population for actual health effects as a result of exposure.

Undertaking and interpreting the results of these monitoring activities requires specialist occupational hygiene and occupational health knowledge.

For more information on evaluation of controls see, for example, CCOHS (2006), Safe Work Australia (2011d) and Work Safe Alberta (2011).

7 Implications for OHS practice

All decisions about hazards and required controls are predicated on knowing the materials involved, how they behave and how they cause damage. Thus the first step for the generalist OHS professional is to identify the chemicals from their labels and link them to SDSs. Informed by a basic understanding of chemicals, chemical states and chemical reactions, together with the information in the SDSs, the generalist OHS professional can determine the nature of the potential harm and how this might be caused. It may be appropriate to consult the HSIS, or other information sources for more detail. If the chemicals are hazardous, details including the chemical name, nature of the hazard, location and quantity should be entered in a chemical register.

The generalist OHS professional may be faced with a situation where workers are expressing signs or symptoms of ill health that may be associated with chemical exposure. Determining the cause and work-relatedness of such ill health may require specialist input in the form of medical evaluations and biological monitoring; however, the generalist OHS professional should be able to apply knowledge of chemicals and their physicobiological action to undertake basic investigations. Such investigations require a logical approach, utilising the SDS and other hazard information on the chemical, exposure assessment, walk-through inspections, and review of patterns and time sequence for development of symptoms. The Bradford Hill (Hill, 1965) criteria for causality are useful for such

investigations. These criteria are listed below with some suggested questions to guide data collection and analysis:

- *Strength of association:* Is there objective evidence of exposure?
- *Consistency of association:* Are the symptoms consistent with SDS information?
- *Specificity of association:* Are the symptoms isolated to one group of workers and/or one site?
- *Temporality:* Can the expression of symptoms be linked in time to exposure? This may be difficult where there is a long latency period for expression of symptoms.
- *Biological gradient:* Are those individuals having the greatest exposure experience more likely to experience symptoms or experiencing more severe symptoms? This may be confounded by individual differences in susceptibility.
- *Plausibility:* Is there a good biological explanation for how the chemical may cause such ill health? A negative response to this question should be treated with caution as the investigator's knowledge may be limited or the state of knowledge may not address this linkage.
- *Coherence:* Is the link between exposure to the chemical and the ill health consistent with known facts?
- *Experiment:* Can the link between the chemical exposure and ill health be tested? Purposeful tests for such links would not be ethical, but evidence may be obtained by comparing sites where the chemical is used with sites undertaking similar work where it is not used.
- *Analogy:* Has something similar occurred with other chemicals, diseases or workplaces?

As stated in section 4.4, where the chemical is hazardous and the controls are known it may be appropriate to move directly to implement the known controls. Alternatively, a risk assessment should be conducted. This may be a qualitative risk assessment based on inspection, observation and workplace consultation, or investigation of incident, first aid and medical reports supported by some basic monitoring. Depending on the nature of the hazard and the complexity of the situation, a quantitative risk assessment may be conducted by an occupational hygienist.

In implementing controls, legislative compliance is the minimum acceptable outcome. The prudent organisation will go beyond regulatory compliance to ensure workers are adequately protected. The long latency of some responses to chemical hazards and the ongoing development of our knowledge of the impact of some chemicals mean that legislative compliance may not provide adequate protection in the long term.

The hierarchy of controls as it applies to chemical hazards is well understood; however, this should not be applied in a simplistic way as the complexity of some situations will

require a range of controls acting as barriers and defences.²⁰ Strategies need to be put in place to monitor the effectiveness of controls.

In managing chemical hazards or investigating disease potentially caused by chemical exposure, the generalist OHS professional may need to liaise with one or more specialists. These may include:

- Certified Occupational Hygienist with expertise in the relevant area for advice on exposure assessment and control
- Dangerous goods consultant²¹ for advice on transport, storage and handling
- Production engineer for safe work practices
- Chemical engineer for engineering controls, particularly at the design phase
- Occupational physician for biological monitoring and health surveillance
- Occupational health nurse who may be the first to receive reports of health effects and who may conduct a range of health surveillance assessments
- Epidemiologist to determine the strength of association between chemical exposure and disease
- Toxicologist to determine safe levels of exposure through health-based risk assessment.

The generalist OHS professional would be expected to orient the specialist to the site, clarify the nature and scope of the work, and facilitate communication with managers, supervisors and operators.

8 Summary

Chemical hazards are a major occupational health and safety issue in Australia. While workers in some industries and some types of workplace have a higher risk of exposure, all workplaces are affected. Chemical hazards are of two main types: reactive and toxic. Identification of the toxic effects of chemical hazards requires an understanding of acute and chronic exposure, and the confounding effect of latency in the expression of signs and symptoms. While the generalist OHS professional may be more likely to be required to address the toxic effects of chemicals, they also should be aware of and understand the hazards, risks and appropriate controls for reactive chemicals. The identification of chemical hazards will be more systematic with the implementation of the Globally Harmonised System for Classification and Labelling of Chemicals.

²⁰ See *OHS BoK Control*

²¹ Membership of the Australian Institute of Dangerous Goods Consultants may be an indication of qualification in this speciality.

Sources of information for hazard identification include the chemical label, the Safety Data Sheet and appropriate hazardous chemical databases. Together with established exposure standards, these sources provide reference points against which workplace information can be compared. Risk assessment requires local knowledge of the chemical state, potential routes of absorption, exposure monitoring results, and the nature of the task, the activity and the worker. The hierarchy of control provides a useful guide to the development of control measures; as with other hazards, there should be a 'package' of controls to create barriers and defences. Ongoing monitoring is required to ensure the reliability of these barriers and defences.

Key thinkers/authors

John Cherrie (UK, chemical exposure models)
John Cocker (UK, biological monitoring)
Roger Drew (Australia, health-based risk assessment)
Martin Harper (US, dusts)
Richard Fenske (US, pesticides and dermal exposure)
Trevor Kletz (UK, chemical safety)
Tony LaMontagne (Australia, chemical hazard interventions)
Andrew Maynard (US, nanoparticles)
Dennis Paustenbach (US, chemical risk assessment and exposure standards)
Mark Piney (UK, chemical hazard control)
Chris Winder (Australia, toxicology and chemical safety)

Key resources

AICHE (American Institute of Chemical Engineers). (2010). Centre for Chemical Process Safety website: <http://www.aiche.org/CCPS/index.aspx>

ATSDR (US Agency for Toxic Substances and Disease Registry). (2011). Toxic substances portal: <http://www.atsdr.cdc.gov/toxprofiles/index.asp>

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