Dusts, Fumes and Fibres

Core Body of Knowledge for the
Generalist OHS Professional

Second Edition, 2022

17.3

OHS Body of Knowledge

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Acknowledgements

The Australian Institute of Health & Safety (AIHS) financially and materially supports the *OHS Body of Knowledge* as a key requirement of the profession. The *OHS Body of Knowledge* forms the basis of the AIHS OHS capability agenda and informs the other platforms of the agenda: education assurance through accreditation; role clarity; capability assurance through individual certification; and continuing professional development. Thus, the *OHS Body of Knowledge* is strategically important to the AIHS and vital for the profession. (www.aihs.org.au/)

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The development of this chapter was supported by an Enforceable Undertaking by J.J Richards & Sons and approved by WorkSafe Victoria. Established as J.J. Richards in 1932, J.J. Richards & Sons is now one of the largest privately owned waste management companies in Australia. Trading as JJ's Waste & Recycling, the company has diversified into specialised areas, including materials recovery and transfer station design and construction, regulated waste collection and treatment, waste disposal/conversion technologies, and environmental education and technical services consultancy.

Bibliography

ISBN 978-0-9808743-2-7

First published in 2023

Authors

Linda Apthorpe, Senior Occupational Hygienist, Hibbs & Associates; Lecturer, Occupational Health and Safety, University of Wollongong

Dr Shahnaz Bakand, Honorary Senior Lecturer, Occupational Health and Safety, University of Wollongong

Dr Jennifer Hines, Senior Occupational Hygienist, EHS Solutions; Lecturer, Occupational Health and Safety, University of Wollongong

Leanne Treadwell, Lecturer, Occupational Health and Safety, University of Wollongong

Jane Whitelaw, Academic Program Director, Occupational Health and Safety, University of Wollongong

Peer reviewers

Carolyn Davis, Independent Consultant, Almondale

Paul Foley, Inspector of Mines, Department of Mines, Industry Regulation and Safety, Western Australia

Dr Dino Pisaniello, Adjunct Professor, School of Public Health, University of Adelaide

Caitlin Purcell, Work Health and Safety Consultant, WHS Foundation

Citation of the whole *OHS Body of Knowledge* should be as:

AIHS (Australian Institute of Health & Safety). (2023). *The core body of knowledge for generalist OHS professionals* (2nd ed.). AIHS.

Citation of this chapter should be as:

Apthorpe, L., Bakand, S., Hines, J., Treadwell, L., & Whitelaw, J. L. (2023). Dusts, fumes and fibres. In Australian Institute of Health & Safety (AIHS), *The core body of knowledge for generalist OHS professionals* (2nd ed.). AIHS.

Dusts, Fumes and Fibres

Linda Apthorpe MScOHP, FAIOH, Certified Occupational Hygienist (COH)®, MFAMANZ
Occupational Hygienist / Lecturer

Linda has more than 25 years' experience providing consulting and laboratory services to a wide variety of workplaces. She has a strong background in analysis and control of workplace hazards such as asbestos, dust and silica. Linda has authored papers and textbook chapters on occupational hygiene and facilitated professional development seminars and training courses on asbestos, silica and occupational hygiene.

Shahnaz Bakand BSc(OccHealth), MSc(OccHyg), PhD
Honorary Senior Lecturer

Shahnaz has worked as an OHS educator and multidisciplinary researcher in Australia and overseas for 30 years. Her PhD research was awarded an Australian Museum Eureka Prize in 2006. As an expert in toxicology and nanotoxicology, Shahnaz has collaborated with the World Health Organization on guidelines for nanomaterials, with her work resulting in policy changes at an international level.

Jennifer Hines BSc(Hons), GDipOH, MScOHP, PhD, FAIOH, Certified Occupational Hygienist (COH)®,
Occupational Hygienist/Lecturer

Jennifer has more than 20 years' experience in improving workplaces for workers. She has worked extensively in heavy industry, including alumina refining, copper refining and smelting, and underground coal mining. Jennifer is the Director of EHS Solutions and combines consultancy with academia to encourage others into the world of occupational hygiene.

Leanne Treadwell BEChem(Hons), MEA, MAIHS
Lecturer

Leanne graduated as a chemical engineer and has worked as an OHS professional in industry and government for more than 35 years in a range of roles in OHS, risk and business management, IT and aged care. She has specialised skills in process safety, major hazard facilities, emergency preparedness and response, and security. Currently, Leanne teaches postgraduate OHS at UOW.

Jane L. Whitelaw MAppSc, GDipOHS, FAIOH, Certified Occupational Hygienist (COH)®, CIH®
Occupational Hygienist / OHS Academic Program Director

Jane had more than 25 years' experience in corporate OHS roles in heavy manufacturing industries before joining UOW in 2009, where she is OHS Academic Program Director and a PhD candidate in the Faculty of Medicine. Jane is a quantitative researcher whose primary area of research is the evaluation of controls for prevention of occupational diseases, with a focus on respiratory illnesses.

Topic Specific Technical Panel

Members of the Topic Specific Technical Panel were selected on the basis of their demonstrated specialist expertise. Panel members were not remunerated; they provided input and critical comment as part of their contributions to the OHS profession and to workplace health and safety.

Pam Pryor	Manager, OHS Body of Knowledge	Australian Institute of Health & Safety
Scott Campbell	Group Safety Manager	JJ's Waste & Recycling
Carolyn Davis	Independent Consultant	Almondale
Paul Foley	Inspector of Mines	Department of Mines, Industry Regulation and Safety, Western Australia
Paul Mayne	WHS Manager	LORA Inland Rail Program, Laing O'Rourke
Caitlin Purcell	Work Health and Safety Consultant	WHS Foundation

OHS Professionals Forum

The following people provided input via an online forum on this chapter's topic and content, particularly the practical implications. The Australian Institute of Health & Safety is appreciative of their time and interest.

Gerry Ayers	OHS&E Manager	CFMEU C&G Division, Vic/Tas Branch
Paul Mayne	WHS Manager	LORA Inland Rail Program, Laing O'Rourke
Anthony Powell	Business Partner	Ballarat City Council
Howard Jeffery-Wright	Zero Harm Lead	Downer
Simon Roberts	Manager, Health & Safety	Fortescue Future Industries
James Smith	Senior Health & Safety Manager	Light Rail Stage 1, Laing O'Rourke

Dusts, Fumes and Fibres

Abstract

Dusts, fumes and fibres have been part of many workplaces since ancient times. The longevity of the problem does not mean that it is necessarily well controlled in present-day workplaces. Indeed, in recent times, we have seen the resurgence of well-known diseases linked to exposure to dust, fumes and fibres. While some aspects of the identification, evaluation and control of these hazards require specialist expertise, generalist OHS professionals have a key role to play in ensuring the health and safety of workers potentially exposed. This chapter is one in a suite of four *OHS Body of Knowledge* chapters addressing chemical hazards. It provides insight into how dusts, fumes and fibres impact the health of workers and how exposures may be evaluated and controlled. It supports OHS professionals in applying a collaborative approach to the management of dust, fumes and fibres, calling on specialist expertise as appropriate.

Keywords

Dust, fume, fibre, aerosols, air monitoring, airborne contaminant, exposure assessment, health, occupational hygiene, particles, risk management, toxicity

Contextual reading

For context, readers should refer to *OHS Body of Knowledge* 1 *Preliminaries* for a full list of chapters and authors and a synopsis of the OHS Body of Knowledge. Chapter 2, *Introduction* describes the background and development process while Chapter 3, *The Generalist OHS Professional: International and Australian Perspectives* describes the role and professional environment.

Terminology

Depending on the jurisdiction and the organisation, terminology refers to 'Occupational Health and Safety' (OHS), 'Occupational Safety and Health' (OSH) or 'Work Health and Safety' (WHS). In line with international practice, this publication uses OHS with the exception of specific reference to the Australian Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application

This chapter includes reference to Australian work health and safety legislation. This is in line with the Australian national application of the *OHS Body of Knowledge*. Readers working in other legal jurisdictions should consider these references as examples and refer to the relevant legislation in their jurisdiction of operation.

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1 Introduction

Dusts, fumes and fibres (DFF) have been a part of workplaces since the building of the seven wonders of the ancient world. Recognition, evaluation and control of worker exposure to DFF are important aspects of the work of generalist occupational health and safety (OHS) professionals. Over time there has been increased demand for knowledge about DFF across an ever-widening range of industries. This knowledge is particularly important in industries such as mining, manufacturing and construction, and in new and evolving areas such as nanomaterials.

This chapter is one in a suite of *OHS Body of Knowledge* (*OHS BoK*) chapters on chemical hazards.[1] It focuses on the particular substances that present as dusts, fumes or fibres, and aims to provide insight into how DFF impact the health of workers and how exposures may be evaluated and controlled. It supports OHS professionals in applying a team approach to the management of DFF by highlighting the role of experts such as occupational hygienists and providing insight into when and how such specialists can support OHS practice. Related areas of bioaerosols, mists, gases and vapours are addressed in other *OHS BoK* chapters.[2] The impact of DFF exposure on workplace visitors and the general community is not specifically covered in this chapter.

After clarifying relevant terminology, the chapter provides a historical perspective on DFF (section 2) and considers the extent of the associated health problem (section 3). The biophysical nature of exposure and response are explored (section 4) and relevant legislation and standards are reviewed (section 5) as the basis for discussion of risk assessment (section 6) and prevention and control, including a case study (section 7). The chapter concludes with implications for OHS professional practice (section 8) and a summary (section 9).

1.1 Terminology and definitions

This section defines key terms used in this chapter. Firstly, the collective term *airborne contaminants* is explained to clarify how dusts, fumes and fibres differ from other airborne contaminants. Secondly, the DFF subset of airborne contaminants is elucidated in Table 1.

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[1] *OHS BoK* 17.1 Managing Chemical Hazards outlines the general principles of managing chemical hazards; *OHS BoK* 17.2 Health Impacts of Chemical Hazards addresses toxicology; and *OHS BoK* 17.4 Process Hazards (Chemical) focuses on the physical effects of chemicals that result from the reactivity of chemicals that may cause immediate damage to people, property or the environment.

[2] See *OHS BoK* 17.2 Health Impacts of Chemical Hazards, *OHS BoK* 17.4 Process Hazards (Chemical) and *OHS BoK* 18 Biological Hazards.

Safe Work Australia (2019, p. 6) defined *airborne contaminant* as:

> …a contaminant in the form of a fume, mist, gas, vapour or dust, and includes microorganisms. An airborne contaminant of this type is a potentially harmful substance that is either not naturally in the air or is present in an unnaturally high concentration and to which workers may be exposed in their working environment.

While airborne contaminants in the workplace mainly originate from hazardous chemical agents, they may also be derived from biological hazards (e.g. Alif et al., 2020). "Various physical, chemical and dynamic processes may generate air pollution [contaminants] leading to emission of gases, particulates or mixtures of these into the atmosphere" (Hayes & Bakand, 2010, p. 462). Based on their physical state, airborne contaminants are often classified into two categories (Winder, 2004):

- Aerosols (suspended air pollutants)
    - Are comprised of small solid or liquid particles that are suspended in air and include dust, fume, fibre, mist and smoke
    - Are classified based on their physical nature, particle size and method of generation
    - Can be inhaled into the respiratory system; the depth they reach depends on particle size.
- Gases and vapours (dissolved air pollutants)
    - Gases are molecules that have no fixed shape or volume
    - Vapours exist in a gas phase as molecules that arise from substances that are liquid or solid at room temperature
    - Can reach and impact all parts of the respiratory system.

Table 1: Characteristics, particle description and examples of dusts, fumes and fibres[3]

Type	Characteristics	Particle description	Examples
Dusts	Finely divided matter in solid form dispersed in the air; the particles are usually produced when a parent material is crushed or subjected to other mechanical processes such as grinding, cutting, sawing, screening or sieving.	Non-spherical in shape. Size ranges from a few nanometres (nm) (i.e. nanoparticles) to >100 micrometres (μm).	May originate from: • Inorganic minerals, e.g. silica, coal • Organic materials, e.g. wood, grain.
Fumes	Very fine solid particles suspended in the air; the particles are generated by	Mostly spherical.	High-temperature operations such as

[3] Sources: Apthorpe and Hines (2020), SWA (2013) and Winder (2004). See also *OHS BoK* 17.1 Managing Chemical Hazards and *OHS BoK* 17.2 Health Impacts of Chemical Hazards.

Type	Characteristics	Particle description	Examples
	thermal (hot) processes often when materials from melted substances, typically metal, volatilise (e.g. welding); may also be formed from high-temperature combustion (e.g. diesel engines, bushfires, cigarettes but not e-cigarettes as these are a vapour). *Note:* The term fume can be confusing if not used correctly, e.g. 'paint fumes' is a misnomer because gases and vapours or mist droplets are not solids and thus not classified as fumes.	Extremely small, usually <0.1μm. Size can increase by aggregation or flocculation as the fume ages.	arc welding, torch cutting and metal smelting.
Fibres	Elongated or thread-like solid particles; the aspect ratio of respirable fibres influences their ability to become airborne and deposit in the respiratory system when inhaled	Fibres have an aspect ratio (length to width) of >3:1. Usually >5 μm in length and <3 μm in width.	Two main fibre types: • Natural, e.g. asbestos, cotton • Man-made vitreous fibres (MMVF),[4] e.g. glass, or composite fibres, e.g. Kevlar®.

2 Historical perspective

The timeline below identifies some key contributors to the development of our knowledge of chemical hazards, particularly DFF.[5]

c.460–370 BCE	Hippocrates	Greek scholar who first documented occupational disease; identified lead poisoning in miners and metallurgists.
c.90–20 BCE	Marcus Vitruvius Pollio	Roman architect/engineer who noted lead workers had pale grey complexions and made the connection to their occupation.
23–79	Pliny the Elder	Roman scholar who identified and documented health risks to those working with zinc and sulphur and described the use of sheep bladder

[4] MMVF were previously referred to as synthetic mineral fibres (SMF).

[5] Sources: ACGIH (2022), Brandys & Brandys (2008), Cherniack (2021), Golec (2020), Paustenbach et al. (2011) and Steer & Langley (2020).

		masks to protect from mercury, dust and vapours.
1494–1555	Georgius Agricola	German physician who authored *De Re Metallica,* a treatise on the mining industry in which he warned that mine "dust which is stirred and beaten up by digging penetrates into the windpipe and lungs, and produces difficulty in breathing, and the disease which the Greeks call [asthma]. If the dust has corrosive qualities, it eats away the lungs, and implants consumption in the body; hence in the mines of the Carpathian Mountains women are found who have married seven husbands, all of whom this terrible consumption has carried off to a premature death."
1493–1541	Paracelsus	Swiss physician who challenged traditional methods of studying medicine and respiratory diseases and determined that 'miners' disease' was caused by inhaling metal vapours and not a punishment of sin by mountain spirits; often described as the 'father of toxicology'.
1633–1714	Bernardino Ramazzini	Italian physician whose book *De Morbis Artificum Diatriba (Diseases of Workers)*, first published in 1700, included chapters on chemicals, dusts and metals and described 52 occupations; recommended hygiene, posture, ventilation and protective clothing for workers; often described as the 'father of occupational medicine'.
c.1760–1840	Industrial Revolution	Introduced new methods of manufacturing (incl. machines, steam and water power, chemicals and mechanised factories); occupational diseases became accepted as associated risks, e.g. pneumonoconiosis (quarrying and mining), silicosis (pottery making, metal casting and tunnelling), byssinosis (yarn and fabric manufacturing), scrotal cancer (chimney sweeping) and 'phossy jaw' (matchstick manufacturing).
1833–1842	UK legislation	The UK *Factory Act 1833* introduced labour laws and required dilution ventilation of some trades; followed by further legislation, e.g. the *Mines and Collieries Act 1842.*

1840	French policy	France issued a policy discouraging the use of lead as a pigment in paint.
1912	Development of exposure standards	German pharmacologist and toxicologist Rudolf Kobert published a list of acute exposure limits for 20 substances.
1916-1917		Occupational exposure limits (OELs) for quartz of 8.5 million particles per cubic foot of air (mppcf) and 10 mppcf were set in South Africa and the United States, respectively, but application was not immediate. An example of failure to protect workers from a known hazard occurred in the early 1930s during construction of the Hawks Nest Tunnel in West Virginia where about 3,000 workers were grossly overexposed to crystalline silica, resulting in an estimated 1,000 deaths.
1941	American Conference of Governmental Industrial Hygienists (ACGIH)[6]	Established a committee for investigating, recommending, and annually reviewing exposure limits for chemical substances; subsequently published lists of maximum allowable concentrations (MACs) that were renamed threshold limit values (TLVs) in 1956;[7] the list now includes more than 700 chemical substances and physical agents and more than 50 biological exposure indices (BEIs)
Late-20th century – early-21st century	Australian legislation	Legislation largely followed the industry-based UK model, with prescriptive regulations to control specific hazards.
From 1980	Australian workplace exposure standards	Exposure standards were legislated for the first time in Australia (section 5.1).
2019	Australian Government	Establishment of the National Dust Disease Taskforce (NSW).

[6] The ACGIH was known as the National Conference of Governmental Industrial Hygienists until 1946 (ACGIH, 2022) https://www.acgih.org/about/about-us/history/).

[7] "Despite…warnings by the ACGIH that TLVs should not be used for compliance purposes, in 1968, the TLV list was adopted by the Occupational Safety and Health Administration (OSHA) as US federal law (Golec, 2020).

Clearly, enormous gains have been made in our understanding of how DFF can impact humans, and improvements have been enforced by regulations and legislation. However, the focus needs to be maintained on compliance and continuous improvement to ensure that historical lessons are not lost and issues repeated. Continued risk assessment, control of exposures to DFF, health monitoring and implementation of new practices as they are developed, will help mitigate and minimise workplace exposures to DFF.

3 Extent of the problem

Since ancient times, clusters of occupational illnesses related to specific industries and hazards have occurred. For example, asbestos-related lung disease was prevalent in the mid-to-late 20th century. Indeed, mining of blue asbestos at Wittenoom Gorge, Western Australia, has been described as Australia's worst industrial disaster (e.g. Steer & Langley, 2020). Of 6,908 people who worked at Wittenoom between 1943 and 1966, 315 had died from mesothelioma[8] by 2008 (Berry et al., 2012). The toll from this disaster continues, with a disproportionately high incidence of malignant mesothelioma among Aboriginal people living in the region impacted by the Wittenoom mining operation (Franklin et al., 2016).

Changes in technology, inadequacy of risk management and complacency have led to a resurgence of some past hazards. For example, in the 1990s and early 2000s, coal workers' pneumoconiosis (CWP or 'black lung') was thought to be a disease of the past in Australia; however, cases of this untreatable, but preventable, lung disease have increased since 2016 (Zosky et al., 2016).

> CWP is a long-latency disease that gradually develops over a prolonged period of exposure to respirable coal dust. … The level of risk of CWP in coal mine workers is dependent on the mine's ventilation and dust suppression strategies. Mine workers who are protected by working in enclosed machine cabins or those who work in open cut mines usually have less exposure to coal mine dust compared to those who work in underground mines. (Alif et al., 2020, pp. 15-16)

In the US, resurgence of CWP since 2000 has been attributed to "changes in the physiochemical characteristics of the dust, reduction in dust suppression activities, and increased workload (i.e. increased exposure)" (Zosky et al., 2016).[9]

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[8] Asbestos is the main cause of mesothelioma, which is "a cancer of the protective lining of the body cavities and internal organs, such as the lungs, heart and bowel" (AIHW, 2018).

[9] See *OHS BoK* 6 Global Concept: Health for information about the resurgence of CWP in Queensland.

Another example is the recent resurgence of accelerated silicosis in engineered stone workers[10] resulting from high and largely uncontrolled exposures to respirable crystalline silica.

> Silicosis is caused by inhalation of respirable crystalline silica generated when manipulating – cutting, grinding and polishing – material containing silica such as engineered stone. The re-emergence of silicosis has been mostly driven by the popularity of engineered stone material which has been available in Australia since the early 2000s. … There is evidence to suggest that nearly one in four engineered stone workers who have been in the industry since before 2018, are suffering from silicosis or other silica dust related diseases. (National Dust Disease Taskforce, 2021, p. 7)

Due to the demand for cheaper stone slabs and less reliance on natural resources such as marble, engineered stone is now commonly used for kitchen and bathroom benchtops. The industry is characterised by small businesses that typically have limited resources to undertake formal risk assessments and apply suitable control measures (National Dust Disease Taskforce, 2021). In addition to silicosis, exposure to silica dust from engineered stone can lead to a range of respiratory diseases including chronic bronchitis, chronic obstructive pulmonary disease (COPD), progressive massive fibrosis and lung cancer (SWA, 2021c).

Asbestosis, pleural plaques, mesothelioma and lung cancer are asbestos-related diseases that contribute to approximately 4000 deaths in Australia each year (Asbestos Safety and Eradication Agency, 2017). Although asbestos use was phased out in Australia from the early 1980s and its use, reuse, sale and importation was banned in 2003, asbestos and asbestos-containing materials still exist within our built and natural environments and Australia continues to experience an increase in asbestos-related deaths (Alif et al., 2020). Also, there remains a risk from inadvertent industrial importation of products made in countries with different standards to Australia. For example, in 2020, asbestos was found in gaskets in imported ferries destined for Sydney Harbour (9News Staff, 2020). Asbestos-related diseases can have a long latency period (20-30 years) and it was estimated that Australia would reach 18,000 cases of mesothelioma by 2020, with another 30,000 to 40,000 cases of other asbestos-related diseases predicted (Gray et al., 2016; Leigh & Driscoll, 2003).

Table 2 lists some diseases related to common DFF with examples of occupations where workers are at risk of exposure. (See also sections 4.2.1 and 4.2.2.) In 2021, SafeWork Australia published an updated *Deemed Diseases in Australia* report based on a systematic review of post-2014 evidence of causal connection between occupational exposure and disease (Driscoll, 2021a,b). The list of diseases includes respiratory diseases that are

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[10] Engineered stone is also known as "composite stone, manufactured stone, artificial stone, reconstituted stone or quartz conglomerate" (SWA, 2021c).

common outcomes of exposure to DFF (including occupational asthma, pneumoconiosis, asbestosis, silicosis, byssinosis and extrinsic allergic alveolitis) and provides information about latency and occupations at risk.

Table 2: Examples of diseases associated with dusts, fumes and fibres and at-risk occupations

Hazard	Main Disease & Nature (A – acute, C – chronic)	At-risk Occupations
DUST		
Coal	Pneumoconiosis – C COPD – C	Coal miners
Crystalline silica	Silicosis – A & C Lung cancer – C	Construction workers, stonemasons, miners
Wood (type dependent)	Nasal & laryngeal cancer – C Allergic reaction – A & C	Timber workers, furniture manufacturers
Flour	Asthma – A & C Allergic reactions – A & C	Bakers
FUMES		
Welding	Metal fume fever – A & C Lung cancer – C	Manufacturing workers, boilermakers/welders
Metals, e.g. lead, zinc, chromium, arsenic	Lung cancer – C	Smelter workers
Diesel emissions (gaseous phase and diesel particulate matter)*	Lung cancer – C Upper respiratory tract irritation – A	Miners, transport workers, construction workers
Second-hand cigarette smoke*	Lung cancer – C	Casino workers
Fire emissions (incl. bushfire smoke)*	COPD – C Lung cancer – C	Fire fighters, rural workers
FIBRES		
Asbestos	Asbestosis – C Lung cancer – C Mesothelioma – C	Asbestos removalists, construction & demolition workers, miners
Man-made vitreous fibre (MMVF)	Upper respiratory tract & skin irritation – A	Construction workers
Cotton (incl. hemp, flax)	Byssinosis – C	Cotton gin workers

*Included due to generation via thermal processes

Occupational asthma has been reported as the most prevalent work-related respiratory disease in developed countries, contributing to "about 15-20% of the overall adult-asthma public burden" (De Matteis et al., 2017, p. 2).

> Asthma affects approximately 2.7 million Australians, and remains a significant cause of death, with more than 400 people dying of asthma in Australia in 2017. … *Work-related asthma* (WRA) is a general term which includes both asthma caused by an inciting exposure in the workplace (occupational asthma, OA) and asthma that is worsened by workplace conditions (work-exacerbated asthma, WEA). … It is estimated that 25% of adults with asthma have WRA. (Hoy et al., 2020, p. 1183).

More than 300 workplace agents have been identified as causes of occupational asthma, including metal salts, dusts and fumes from agents such as cobalt, chromium and nickel and some naturally occurring dusts such as grain and wood dusts (Hoy et al., 2020).

Chronic obstructive pulmonary disease (COPD) is another common condition. Aside from a strong causal link with tobacco smoking, "about 15% of all COPD cases in Western societies have been attributed to exposure to vapours, gas, dust or fumes, mainly based on past occupational studies in the highly exposed mining, textile and farming sectors" (De Matteis et al., 2017, p. 2).

> COPD is becoming an increasingly important type of OLD [occupational lung disease] as more associations with work-related exposure are being identified, but Australian data sources are yet to reflect this increasing importance. Work-related COPD is likely to become more widely recognised in Australia as smoking rates decline. … Estimates of the prevalence of work-related COPD in the Australian population range from eight to 19 per cent. (Alif et al., 2020, pp. 9, 36)

Leung et al. (2020) reported that "COPD patients have increased risk of severe pneumonia and poor outcomes when they develop COVID-19."

Tobacco smoke is a well-known lung carcinogen and "average smokers have a 10-fold and heavy smokers a 20-fold increased risk of developing lung cancer compared with nonsmokers" (Liu & Sun, 2015, p. 190). The International Agency for Research on Cancer (IARC) 2020 statistics revealed that

> With an estimated 2.2 million new cancer cases and 1.8 million deaths, lung cancer is the second most commonly diagnosed cancer and the leading cause of cancer death in 2020, representing approximately one in 10 (11.4%) cancers diagnosed and one in 5 (18.0%) deaths. Lung cancer is the leading cause of cancer morbidity and mortality in men, whereas, in women it ranks third for incidence…and second for mortality, after breast cancer. (Sung et al., 2021, p. 233).

Globally, about two-thirds of lung cancer deaths are attributable to tobacco smoking, with outdoor ambient particulate air pollution and exposures to other inhalable agents responsible for significant proportions (Sung et al., 2021).

Overall, it is difficult to estimate the magnitude of the problem of occupational exposure to DFF in Australia because work-related illness is underreported, and workers' compensation statistics do not capture all associated cases. For example, self-employed workers (about 10% of Australian workers) are generally not covered by workers' compensation schemes and "diseases are under-represented because many diseases result from long-term exposure to agents or have long latency periods, which makes the link between the work-related disease and the workplace difficult to establish" (SWA, 2021a, p. 58). Unless exposure is catastrophic or has acute effects, immediately causing a noticeable reaction, workers may not know they have been exposed or may not connect the onset of disease with earlier workplace exposure. A further complication is the flow-on effect of workplace chemical exposures on workers' family members and community contacts. For example, lead brought home on a worker's clothing is particularly problematic for young children:

> Lead exposure in childhood can cause behaviour and attention problems, learning difficulties and cognitive losses. It may also affect physical growth, blood cell development and the functioning of the kidneys. (NSW Health, 2021).[11]

Alif et al. (2020, p. 9) identified a need for "more longitudinal studies of high-risk workers, involving disease and exposure information, to better identify high risk industries and occupations and assist in more effective targeting of prevention activities." The legislated requirement mandating health monitoring for a range of specific chemicals (SWA, 2022) should increase the knowledge about these hazards.

4 Exposure

While chemicals may enter the body through inhalation, ingestion, injection or absorption through the skin, inhalation is the most significant route of exposure for DFF. The severity of adverse health effects of inhaled chemicals is influenced by several factors such as type of airborne contaminant, concentration, size of particles, solubility in tissue fluids, reactivity with tissue compounds, frequency and duration of exposure, interactions with other airborne contaminants and individual susceptibility (Winder, 2004). Because the respiratory tract is the most vulnerable target organ for many inhaled particles, including DFF, OHS professionals require a general understanding of the structure and function of the respiratory system.[12]

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[11] Also, lead exposure can come from non-occupational sources such as lead paint on toys.

[12] The *OHS BoK* chapter 7.1 *The human: as a biological system* considers the human body as a complex biological system and provides an overview of different biological systems of the human body including the respiratory system.

The respiratory system transfers oxygen to the blood and removes carbon dioxide as a metabolic waste. These processes occur through inhalation, gas exchange and exhalation. The respiratory tract consists of the nasopharyngeal, tracheobronchial and alveolar regions (Figure 1).

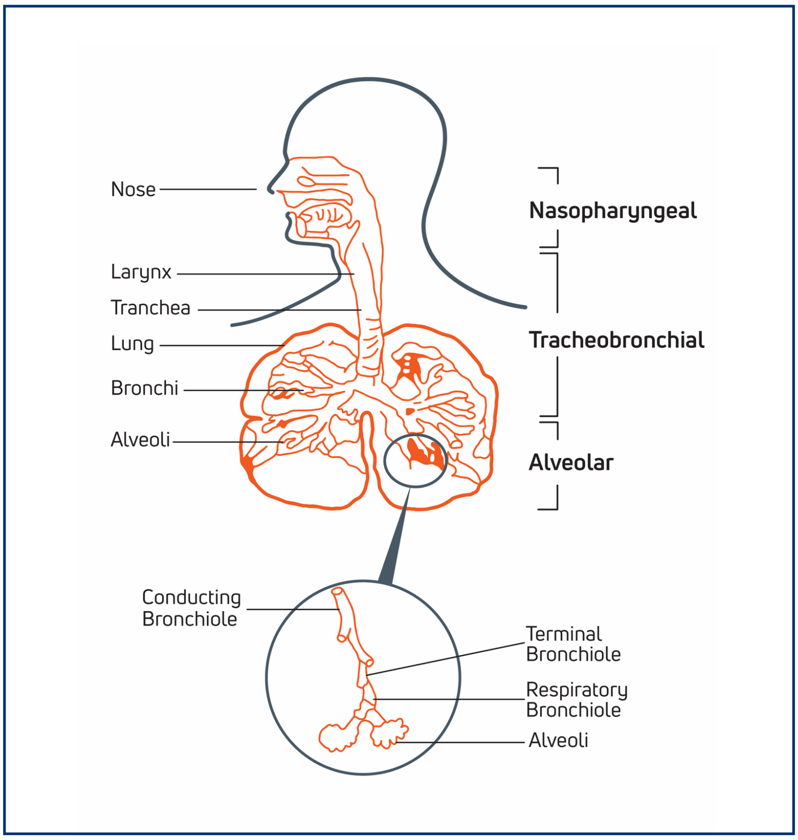

Figure 1: Regions of the respiratory tract (Valentine & Kennedy, 2001)

During inhalation, air is channeled from the nose and the upper airways to the alveolar region of the lung. The alveolar region offers a large surface area (about 140 m^2) and a very thin membrane layer (0.4-2.5 µm), facilitating high daily volume (>10 m^3) of gas exchange and tissue oxygenation (Beckett, 1999; Leikauf, 2019; Liu & Sun, 2015).

4.1 Respiratory tract particle deposition and clearance

The respiratory system contains a series of defense mechanisms including nasal clearance, mucociliary clearance and pulmonary macrophages to remove inhaled particles, including DFF (Leikauf, 2019); however, it does not always cope effectively with the range and/or quantity of airborne contaminants that may occur in workplace environments. Therefore, inhaled DFF may travel to and deposit in different regions of the respiratory tract.

The site of particle deposition will significantly determine the ultimate response of the respiratory tract to inhaled DFF. As well as physiological and anatomical characteristics of the respiratory tract, physicochemical properties of particles and their aerodynamic performance are critical in determining the site of penetration and deposition of inhaled particles. Transport and deposition of particles in the respiratory tract is governed by three main mechanisms – inertial impaction, sedimentation and diffusion (Carvalho et al., 2011; Figure 2).[13]

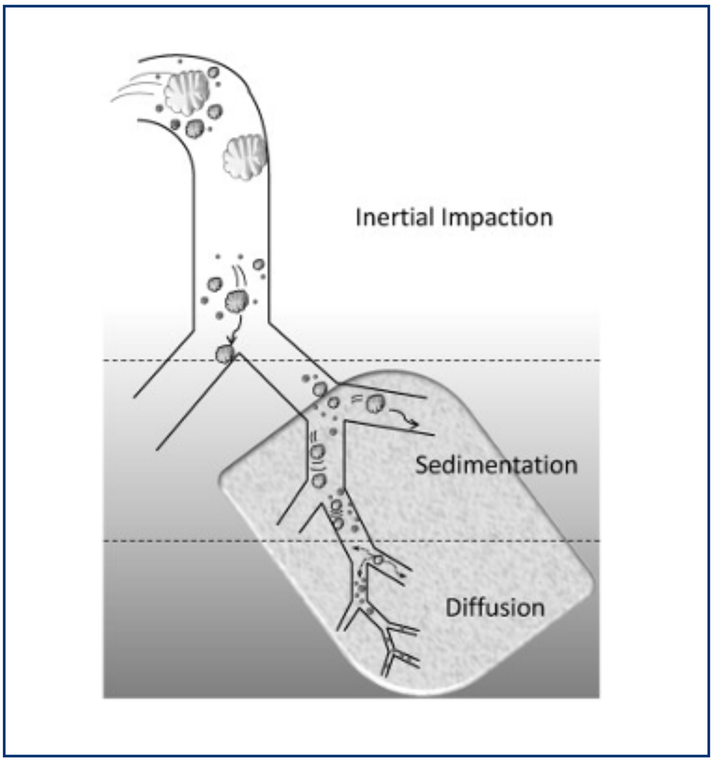

Figure 2: Main mechanisms of particle deposition (Carvalho et al., 2011, p. 2)

[13] In addition to the primary mechanisms of inertial impaction, sedimentation and diffusion, other mechanisms – turbulence, electrostatic precipitation and interception – can contribute to particle deposition (Darquenne, 2020).

During inhalation, very large particles are captured by the filtration effect of nose hairs. The high airflow and directional changes associated with the upper airways facilitate inertial impaction and hence removal of large (>10 µm) particles (Leikauf, 2019). Small (2.5-10 µm) particles that penetrate the upper airways can be deposited in the tracheobronchial region via impaction and sedimentation. Sedimentation may occur where airways are small and air velocity is slow in smaller bronchi, bronchioles and alveolar spaces. Very small particles, including submicron (<1 µm) particles and nanoscale (<0.1 µm) particles, can penetrate deeply into the alveolar region and reach the alveolar epithelium, mainly through diffusion (Leikauf, 2019; Mühlfeld et al., 2008; Oberdörster et al., 2005).

Consequently, particle size is a critical property that determines airborne behaviour and the deposition site of particles in the respiratory tract (Bakand & Hayes, 2016; Liu & Sun, 2015). As particles are often irregular or non-spherical in shape, *aerodynamic diameter* is often used to describe particles, representing "the diameter of a unit density sphere with the same terminal settling velocity as the particle, regardless of its size, shape, and density" (ISO, 1995; Liu & Sun, 2015, p. 185). Particles are classified into three health-related size fractions – inhalable, thoracic and respirable – depending on how deeply they can travel through the respiratory tract and penetrate into the lung (Figure 3).

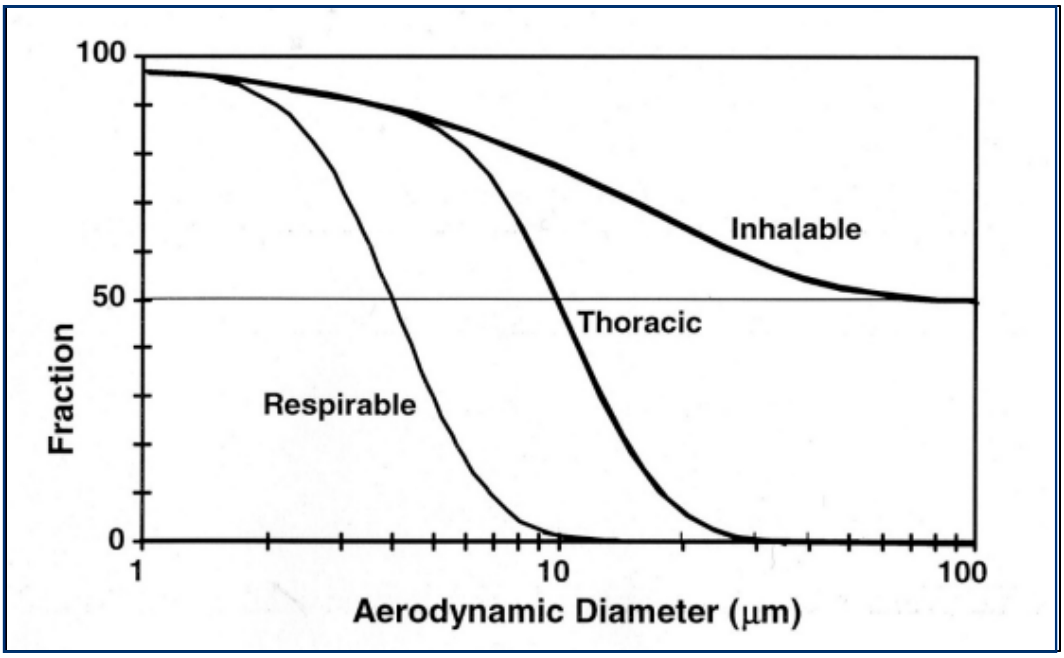

Figure 3: Particle penetration in the respiratory system (Baron, 2016, p. 3)

Inhalation, transportation and deposition of DFF particles in the respiratory tract are size-dependent. The clearance of deposited particles is important and rapid removal minimises the time available to cause damage. Lung defense depends on clearance; however, this does not always provide full protection against adverse effects of inhaled particles (Leikauf, 2019). In addition, very small particles (e.g. nanoparticles) that penetrate deeply into the lung may act as a vehicle to adsorb and carry other workplace co-contaminants or toxic gases and facilitate their access to the blood (Bakand & Hayes, 2016; Borm et al. 2006). It is important to consider possible interactions of such multiple exposures. Figure 4 depicts the relative particle sizes (in microns) for respirable, thoracic and inhalable particles.[14]

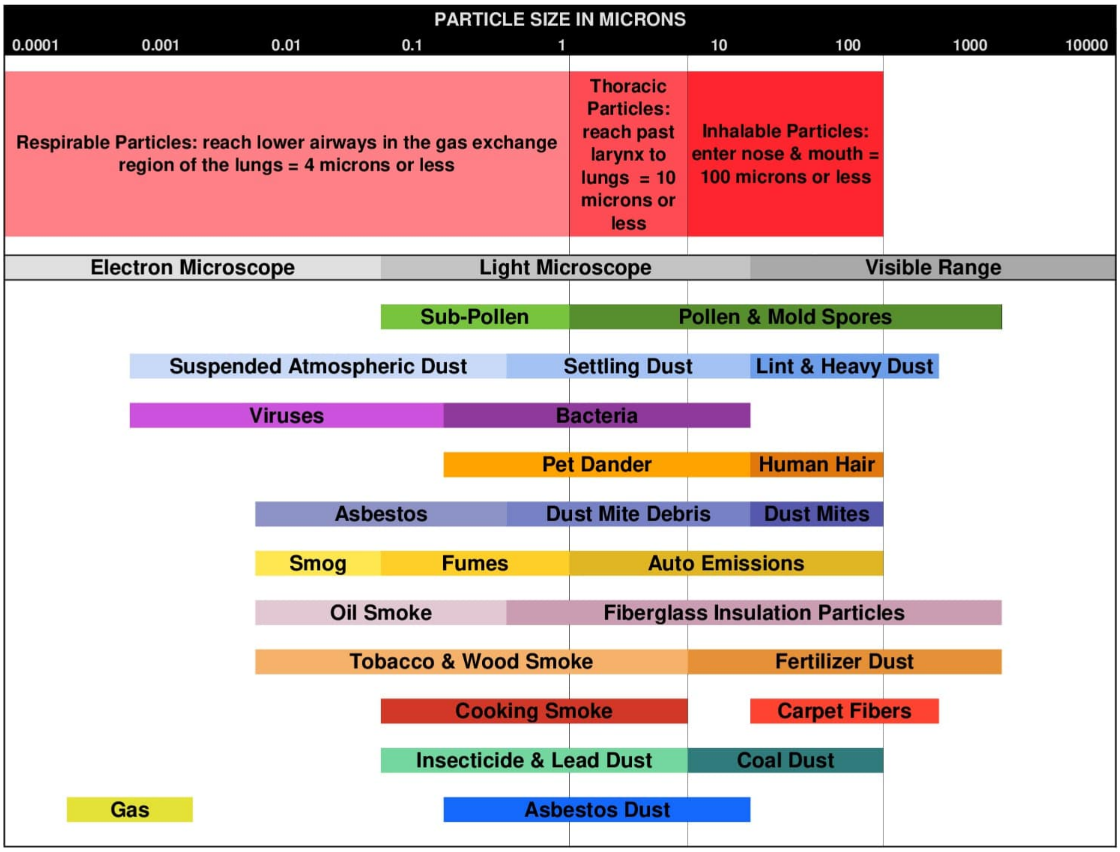

Figure 4: Particle size comparisons (Roberts, 2019)

[14] As defined by *ISO 7708:1995 Air Quality – Particle Size Fraction Definitions for Health-related Sampling* (ISO, 1995), inhalable particles are <100 µm in size and respirable particles are generally <10 µm.

4.2 Responses to exposure

An increase in the exposure level, or dose, of a chemical will generally cause an increase in the biological response and an increase in the number of individuals affected. However, sensitivity to chemicals can vary among individuals; while some may be resistant to specific exposures, others may be quite sensitive, which is an important consideration in risk assessment. The characteristics of exposure and the spectrum of effects come together in a correlative relationship called the dose-response relationship, which is addressed in *OHS BoK* 17.2 Health Impacts of Chemicals[15]

As explained by Eaton and Gilbert (2015), the variation of responses to toxic exposures in a population often exhibits a normal distribution in which a few individuals respond to the lowest dose, and some only respond at the highest dose. Most individuals respond to the intermediate dose, and the maximum response is in the middle. Due to such differences in chemical susceptibility among individuals, a bell-shaped curve known as a normal frequency distribution is observed (Figure 5(a)). Those responding to the lowest dose at the left side of the curve are called hypersusceptible, and those at the right end are called resistant. If the numbers of individuals responding at each consecutive dose are added together, a cumulative, quantal dose-response relationship can be obtained (Figure 5(b)). When sufficient increasing doses are considered, the sigmoid dose-response curve can depict the full spectrum of effects ranging from no effect to increasing effect, and maximum effect levels. Such dose-response models can be used to determine safe and hazardous levels of chemicals and hence, to assess the risk of human exposure to chemicals and inhaled materials.

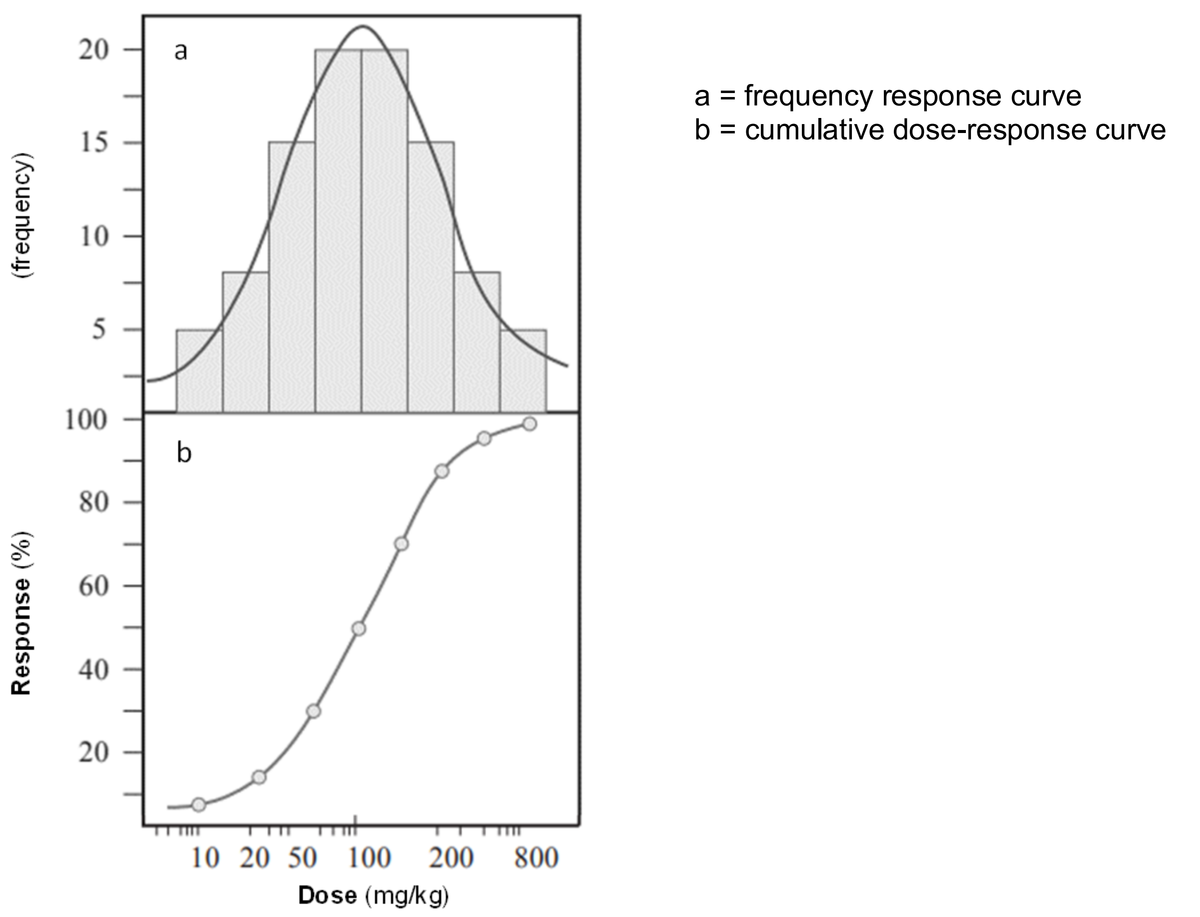

Figure 5: The dose-response relationship (modified from Eaton & Gilbert, 2015, p. 11)

Air pollution research has demonstrated a significant link between exposure to inhaled particulates, mainly ultrafine particles, and increased cardiovascular and pulmonary morbidity and mortality (e.g. Du et al., 2016). Vulnerable populations such as the aged and very young, and those with pre-existing lung conditions are generally more susceptible to such environmental air pollution at lower than workplace exposure levels. In comparison to environmental exposures, it is often assumed that the working population is comprised of healthy adults who can better tolerate workplace exposures than those who are not employed; this is largely due to pre-employment medical screening and is a recognised bias in epidemiology studies known as the 'healthy worker effect' (e.g. Donaldson et al., 2007 pp. 413- 424; Kirkeleit et al., 2013). However, the role of individual susceptibility to carcinogens or allergic reactions to workplace exposures is not yet fully understood.[16] Even the

[16] See *OHS BoK* 7 The Human as a Biological System.

respiratory systems of normally fit and healthy young adults cannot always deal with airborne concentrations that may occur in some workplaces, leading to acute and/or chronic effects. “In addition, the ageing workforce [with a high incidence of] pre-existing respiratory conditions, poses new challenges in terms of the diagnosis and management of occupational lung diseases” (De Matteis et al., 2017, p. 1). Sections 4.2.1 and 4.2.2 provide examples of acute and chronic responses to inhaled DFF.[17]

4.2.1 Acute responses

Airway reactivity

Larger airways of the respiratory tract are surrounded by bronchial smooth muscles that maintain airway tone and diameter during normal breathing. This smooth muscle tone can be affected on exposure to respiratory irritants provoking bronchoconstriction, a condition characterised by a reduced airway diameter and hence increased resistance to airflow (Klaassen et al., 2015). Coughing, wheezing, chest tightness and dyspnea or a feeling of breathlessness are among the symptoms of bronchoconstriction, which often occurs in lung diseases.

Pulmonary edema

Toxic pulmonary edema is an acute lung condition characterised by fluid accumulation in the alveolar tissue and air spaces of the lungs that limits the gas exchange of oxygen and carbon dioxide in the alveoli (Klaassen et al., 2015). Many inhaled materials induce cellular toxicity that may increase permeability of the respiratory membrane leading to the accumulation of fluid in lung tissues (Liu & Sun, 2015). An excess of fluid impairs gas exchange and may lead to respiratory failure and even death. For example, acute exposures to high concentrations of cadmium fumes can cause pulmonary edema (ATSDR, 2012).

4.2.2 Chronic responses

Asthma

Asthma is characterised by bronchospasm, airways mucus and cough due to airway hyperactivity, and an increased response to particular or unknown agents associated with acute and/or chronic effects (e.g. Hendrick et al., 2004; Leikauf, 2019; Lizarralde et al., 2003).

About 25% of asthma cases in adults can be attributed to exposures at work and more than 300 workplace agents have been identified to induce occupational asthma, including metal salts, dusts or fumes from agents such as cobalt, chromium and nickel and some naturally occurring dusts such as grain and wood dusts (Hoy et al., 2020; Leikauf, 2019; Liu & Sun

[17] See *OHS BoK 17.2* Health impacts of Chemicals for a general discussion on acute and chronic exposure.

2015). Prior knowledge about the triggering agent is important in controlling exposure and managing disease.

> Most cases of occupational asthma are allergic in nature and involve [respiratory] sensitisation. … Once sensitisation has occurred, the affected worker may then react to much lower levels of exposure to the sensitiser or to other, nonspecific triggers (such as cold air or exercise). Sensitiser-induced occupational asthma develops because of immune-mediated sensitisation to an occupational agent. … Some cases of occupational asthma are irritant-induced rather than sensitiser-induced. Irritant-induced asthma is less common [and] a non-immunological condition that develops following exposure to certain irritant substances at the workplace. … A wide range of work-related exposures can exacerbate pre-existing asthma symptoms, including chemicals, dusts or allergens. (Alif et al., 2020, p. 13)

COPD

Chronic obstructive pulmonary disease (COPD) is a collective term for common chronic lung conditions that are generally caused by long-term exposure to lung irritants, including DFF, and are characterised by airflow obstruction (Alif et al., 2020). COPD may involve airway and alveolar pathology, mainly leading to chronic bronchitis and emphysema.

> Chronic bronchitis is defined as a productive cough that persists for at least three months over a period of at least two years. Emphysema is defined as an increase in the size of alveolar air spaces within the lung without any fibrosis of the lung tissue. Changes in lung function over time is a significant predictor of COPD and therefore of interest for the early identification of this disease. (Alif et al., 2020, p. 14)

Pneumoconiosis

Pneumoconiosis is a general term to describe chronic lung diseases caused by long-term exposure to mineral dusts that accumulate in the lung (Mapel & Coultas, 2002; Winder, 2004). Benign (or non-collagenous) pneumoconiosis describes the presence of non- or low-toxic materials in the lung: “a range of inorganic materials have been shown not to damage alveolar architecture or give rise to collagenous fibrosis…such as iron ore (siderosis) tin ore (stannosis) and barium compounds (baritosis)” (Winder, 2004, p. 96). Collagenous pneumoconiosis refers to structural alterations in lung tissue and irreversible fibrosis resulting from exposure to mineral dusts such as silica (silicosis), asbestos (asbestosis) and coal dust (coal worker’s pneumoconiosis) (Winder, 2004).

Pulmonary fibrosis

Exposure to DFF can cause pulmonary fibrosis, which may be defined by the presence of an increased amount of newly formed collagen fibres in the alveolar region, alveolar ducts and respiratory bronchioles (Liu & Sun, 2015, p. 189). The formation of collagenous deposits is a complex process and at the central point (foci) of such deposits the inhaled materials such as silica, asbestos or MMVF are often localised (Leikauf, 2019). The fibrotic (i.e. scarred and damaged) lung cannot inflate or deflate properly leading to a restrictive lung disease (Leikauf, 2019). Symptoms include shortness of breath, dry cough, feeling tired, weight loss and nail clubbing. Complications may involve pulmonary hypertension, respiratory failure and lung cancer.

Carcinogenesis and lung cancer
Cancer is a disease of cellular mutation and abnormal cell growth, and a carcinogen is an agent capable of inducing cancer (Klaunig, 2014). There are multiple causes of cancer such as chemical, physical and viral agents, and exposure to carcinogens may occur via occupational, environmental, pharmaceutical and lifestyle factors (Klaunig, 2014).

Many workplace chemicals are recognised as lung carcinogens. Some toxicants, such as formaldehyde and some types of wood dust, may cause cancer in the upper respiratory tract (Winder, 2004). Asbestos, respirable crystalline silica, arsenic and metal dusts or fumes (e.g. nickel, beryllium, cadmium and chromium) have been associated with an increased risk of lung cancer (Liu & Sun, 2015). In many occupational settings, exposures to multiple carcinogens may occur, "such as the combination of silica dust and the carcinogen radon present in uranium mines" (Bohle & Quinlan, 2000, p. 23). The risk of developing lung cancer is significantly increased in smokers exposed to asbestos fibres, "suggesting a synergistic interaction[18] between the carcinogens" (Liu & Sun, 2015, p. 191).

5 Legislation and standards

In addition to the general duties requirements set out in the the *Model Work Health and Safety Regulations* (SWA, 2022),[19] the WHS Regulations detail specific requirements relating to airborne contaminants that include requirements to ensure exposure standards are not exceeded (s 49), to monitor airborne contaminant levels (s 50), and to provide health monitoring where there is a significant risk to a worker's health because of exposure to a hazardous chemical (s 368) (SWA, 2022).

The WHS Regulations (SWA, 2022, ss 49, 50) require persons conducting a business or undertaking (PCBUs) to

> …ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture [and to]
> …ensure that air monitoring is carried out to determine the airborne concentration of a substance or mixture at the workplace to which an exposure standard applies if:
> (a) the person is not certain on reasonable grounds whether or not the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure standard; or
> (b) monitoring is necessary to determine whether there is a risk to health.

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[18] Synergism is "Where both chemicals individually have an effect and where the total effect is greater than an additive effect" (SWA, 2019, p. 7).

[19] See *OHS BoK* 9.2 Work Health and Safety Law in Australia for a discussion of the general duties under the legislation and the associated interpretation of *reasonably practicable*.

The health of a worker must be monitored if they are “using, handling, generating or storing hazardous chemicals and there is a significant risk to the worker’s health because of exposure to a hazardous chemical” (SWA, 2022, s 368). The chemicals for which health monitoring is required are specified in Schedule 14 of the WHS Regulations together with the type of monitoring required, including requirements for engagement of a registered medical practitioner with experience in health monitoring.[20] It should be noted that these are the minimum standards and not an exhaustive list and so should not be relied on by PCBUs as fulfilment of their legal duties under WHS law. It would be prudent to conduct health monitoring (e.g. regular standardised respiratory function tests) where other recognised hazards exist, including exposure to DFF not otherwise classified.[21] (See section 6.3.)

Also, the WHS Regulations detail specific requirements for the management of hazards relating to lead (Part 7.2) and asbestos (Parts 8.1 to 8.10) and, under Schedule 10, some carcinogens are prohibited or restricted (SWA, 2022).[22] Carcinogens that occur as a by-product of a work process must also be considered when identifying hazards in the workplace[23] and there are specific duties related to prohibited or restricted carcinogens and a carcinogen may not be acceptable for use in Australia.[24]

It is the responsibility of the PCBU to be familiar with the legislation and regulations that apply in their particular jurisdiction[25] and industry, and to implement appropriate reporting systems to ensure adequate records are kept and regulators notified of reportable instances/diseases (e.g. notification of lead in blood levels or diagnosis of asbestosis or silicosis).

All jurisdictions in Australia provide some form of workers’ compensation scheme for incapacity or permanent impairment due to exposure to DFF; individual state and territory legislation should be reviewed for specific reporting and compensation allowances (SWA,

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[20] For more information, see the *Health Monitoring Guide for Medical Practitioners* (SWA, 2020b).

[21] Some requirements may be industry specific; e.g. in NSW, coal mining workplaces are governed by the *Work Health and Safety Act 2011* (NSW Government, 2020) and regulated through the *Work Health and Safety (Mines and Petroleum Sites) Act 2013* (NSW Government, 2013) and the *Work Health and Safety (Mines) Regulation 2014* (NSW Government, 2014).

[22] Each State or territory may operate Schedule 10 differently and OHS professionals should ensure familiarity with the application in their state or territory.

[23] Safety Data Sheets provide information on carcinogenicity.

[24] Importers or manufacturers of industrial chemicals should notify the Australian Industrial Chemicals Introduction Scheme (AICIS, www.industrialchemicals.gov.au/) prior to importing or manufacturing (introducing) industrial chemicals and follow their guidelines to promote the safe use of chemicals, including those that may pose potential carcinogenicity. (AICIS replaced NICNAS in July 2020.)

[25] For example, state legislation varies in the adoption of the workplace exposure standards (section 5.1).

2018a). For example, the NSW *Workers' Compensation (Dust Diseases) Act 1942* (NSW Government, 2019) outlines the structure and duties of the Dust Diseases Board, Queensland has a Notifiable Dust Lung Disease Register (Queensland Health, 2020) and there is a stand-alone Australian Mesothelioma Registry (AIHW, 2018).

5.1 Occupational exposure limits

Internationally, there is a wide variety of terminology used to describe workplace exposure limits to hazardous chemicals. Examples are provided in Table 3.

Table 3: Example terminology for exposure standards

Country/Agency	Acronym	Description
Australia & New Zealand	WES	Workplace Exposure Standard[26]
European Commission	OEL	Occupational Exposure Limit
United States: ACGIH	TLV®	Threshold Limit Value
United States: Occupational Health & Safety Administration	PEL	Permissible Exposure Limit
United States: National Institute for Occupational Safety & Health	REL	Recommended Exposure Limit
United Kingdom: Health & Safety Executive	WEL	Workplace Exposure Limit

Although many countries have adopted the ACGIH TLVs® as the basis for their exposure standards and health laws, as yet there is no global consistency (e.g. Golec, 2020). The *National Model Regulations for the Control of Workplace Hazardous Substances* (NOHSC, 1994) formed the basis for hazardous substances regulation in Australia as legislated in some jurisdictions.[27] This was reinforced by the WHS Regulations, which mandated workplace exposure standards (WES), that is, "the airborne concentration of a particular substance or mixture that must not be exceeded" (SWA, 2013, p. 5).

WES are set considering a variety of factors, including the weight of evidence for a critical outcome determined via peer-reviewed scientific data on chemical toxicity based on animal

[26] This title is likely to change to Workplace Exposure Limit in 2023.

[27] See *OHS BoK* 17.1 Managing Hazardous Chemicals (in development at the time of writing) for the background and current status of regulatory requirements, including the Globally Harmonised System of Classification and Labelling of Chemicals.

or human experiments and workplace studies (SWA, 2018c). Following regulatory impact analysis and a period of public comment and feedback, Safe Work Australia adopt the WES and list them in the Hazardous Chemical Information System (HCIS). WES become mandatory when adopted into law by state and territory jurisdictions.[28]

Safe Work Australia (SWA, 2019) defined three types of WES:

- *Eight-hour time-weighted average (TWA)* – "the maximum average airborne concentration of a substance when calculated over an eight-hour working day, for a five-day working week" (p. 6).
- *Short-term exposure limit (STEL)* – "the time-weighted average maximum concentration of a substance calculated over a 15-minute period" (p. 6). "Exposures at the STEL…must not be repeated more than four times per day [and] must be at least 60 minutes between successive exposures at the STEL" (pp. 7-8).[29]
- *Peak limitation* – "a maximum or peak airborne concentration of a substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes" (p. 6).

Also, chemicals with WES are classified according to advisory carcinogen category (i.e. known, presumed or suspected carcinogen) or have a further notation as:

- *Skin* – where "absorption through the skin may be a significant source of exposure" (p. 10)
- *Respiratory sensitiser* – "a substance that leads to hypersensitivity of the airways after being inhaled" (p. 12)
- *Skin sensitiser* – "a substance that leads to an allergic response after skin contact" (p. 12). (SWA, 2019)

It is important to appreciate that WES:

- Are based on current knowledge and can change over time based on new information from epidemiological and toxicological studies
- Relate to the concentration of an airborne contaminant in the worker's breathing zone
- Are designed to be effective for "nearly all workers," i.e. some will be susceptible to adverse effects at lower concentrations, however, as workplace standards are reviewed they may be set at the no observable effect level
- Are not a dividing line between safe and unsafe
- Require adjustment for workers with extended shifts[30] (Golec, 2020; SWA, 2013,

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[28] See www.safeworkaustralia.gov.au/safety-topic/managing-health-and-safety/workplace-exposure-standards-chemicals/review-workplace-exposure-standards

[29] "STELs are established to minimise the risk of intolerable irritation, irreversible tissue change [and] narcosis to an extent that could precipitate workplace incidents" (SWA, 2013, p. 6).

[30] See *Adjustment of Workplace Exposure Standards for Extended Work Shifts* (AIOH, 2016) for information about the required adjustments.

2020b).

The model WHS Regulations (as at 14 April 2022) Part 3.2, Division 7, ss 49 and 50 (SWA 2022b) require PCBU's to "ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture." and to ensure that air monitoring is carried out if there is any uncertainty that exposure standards may be exceeded or "monitoring is necessary to determine whether there is a risk to health". State legislation varies in the adoption of the WESs and it is important to refer to the latest regulations for your jurisdiction

6 Risk assessment

It may be difficult to perform a risk assessment for events that have gradual or time-delayed consequences such as exposure to asbestos fibres.[31] In such cases, the measure of risk depends on statistical models for the potential onset of the disease and the level of disease that could be exhibited by the workforce. This should not deter the inclusion of chronic effects from DFF in risk profiles and the management of these issues alongside other risks in site risk registers. This section outlines types of surveys and measurement techniques commonly used in occupational exposure assessments and reviews DFF-specific strategies for air monitoring and health monitoring.[32]

The assumptions made in any quantitative or qualitative risk assessment should be documented, considered part of the overall risk assessment and revisited as new information becomes available (e.g. Flage & Askeland, 2020). In cases where data are insufficient, highly conservative or contentious, a consequence assessment should still be undertaken and controls utilised to ensure that the worst credible case consequence is being managed. The most important element of risk control is ensuring that all controls that are reasonably practicable are in place (SWA, 2013). This applies to both acute impacts and chronic diseases. In situations where there is insufficient information about a hazard, the precautionary principle[33] should be applied when assessing and managing workplace risks. For example, control banding (section 7.1) may be used to determine the type and level of

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[31] See *OHS BoK* 31.1 Risk.

[32] Detailed information about conducting risk assessments can be found in *ISO 31000:2018 Risk Management – Guidelines* (ISO, 2018); *How to Manage Work Health and Safety Risks: Code of Practice* (SWA, 2018b); and *Simplified Occupational Hygiene Risk Management Strategies* (Firth et al., 2020). Also, *OHS BoK* 31.1 Risk outlines general principles and limitations of risk assessments.

[33] See *OHS BoK* 34.1 Prevention and Intervention for a discussion on the precautionary principle.

controls for some nanoparticles.[34] In some situations, the risk assessment may not require evaluation as it is obvious controls must be implemented as a priority. Air monitoring may then be necessary to determine the effectiveness of the controls.

As new chemicals and processes are invented, and even with existing materials and processes, new hazards may present as emerging issues requiring risk assessment (SWA, 2018b). It is often only as a result of worker illness or disease within an industry or worker cohort that the identity and impact of the new hazard becomes evident.

6.1 Exposure assessment strategies

When undertaking hazardous chemical risk assessments, evaluation of the agent is often required to understand the risk it poses. Also, it is a legislative requirement for a PCBU to ensure that worker exposure to airborne contaminants such as DFF do not exceed the WES (section 5). Other reasons for evaluation of DFF in workplaces may include to address worker concerns or complaints, to comply with notices from regulatory authorities or to determine if health monitoring is required. The information gathered is mostly used to establish if existing control measures are adequate or require improvement.

The assessment may be qualitative, quantitative or both. Information may be gathered via observation, interviewing key stakeholders (i.e. management, supervisors and workers) and/or by conducting measurements. General principles include:

- Establish a clear purpose prior to commencing any assessment to ensure that the methods and outcomes meet the desired aim
- Confirm that the methods and equipment are validated and fit for purpose
- Utilise the services of a NATA accredited laboratory for the specific analysis required
- Seek expert advice as required.[35]

[34] *OHS BoK* 34.1 Prevention and Intervention. See also *OHS BoK* 33 Models of Causation – Health Determinants for information on evidence-based models of work-related disease/disorder causation.

[35] Certified Occupational Hygienists (COH)® have the skills and knowledge to plan assessments, to undertake measurements using validated methodologies, to interpret the results, to provide recommendations for controls contextualised to the workplace scenario, and to assist in communicating the results to the workplace.

6.1.1 Types of surveys

Initial or *walk-through surveys* are simple assessments of the work area to identify potentially hazardous agents present in raw materials, or hazards generated by the process such as the products themselves, by-products and waste materials. Walk-throughs help to:

- Inform priority areas of concern
- Identify types of hazards present
- Understand potential routes of entry and health effects, including interaction of hazard(s) and worker(s)
- Recognise work groups where measurements are required
- Observe controls currently utilised in the workplace.

Measurement surveys are undertaken when an initial survey has identified exposure scenarios for workers and where measurements are required to determine the adequacy of control measures. Measurement results can be used to:

- Identify the source or problem (e.g. the presence of certain agents within the workplace)
- Determine the magnitude of the problem (e.g. the airborne concentration of agents)
- Establish whether current controls are required/effective with respect to WES for the agents present (i.e. compliance monitoring).

Measurement survey strategies include:

- *Personal* or *exposure monitoring* where worker exposures are assessed by sampling that occurs within the breathing zone[36] of the worker (Figure 5). When conducted over a representative period of time, the results of personal sampling for airborne contaminants such as DFF can be compared to the relevant WES.

- *Static* or *positional sampling* where the sampling equipment is located in a fixed position for the duration of the sampling. Results from static samples can assist with determining the airborne concentrations at the source or other strategic locations and the effectiveness of controls. Results from this type of sampling MUST NOT be compared to WES as the sample is not taken within the breathing zone of the worker and is therefore not indicative of worker exposure.

[36] The breathing zone is defined as "a hemisphere of 300 mm radius extending in front of a person's face and measured from the midpoint of an imaginary line joining the ears" (SWA, 2019, p. 6).

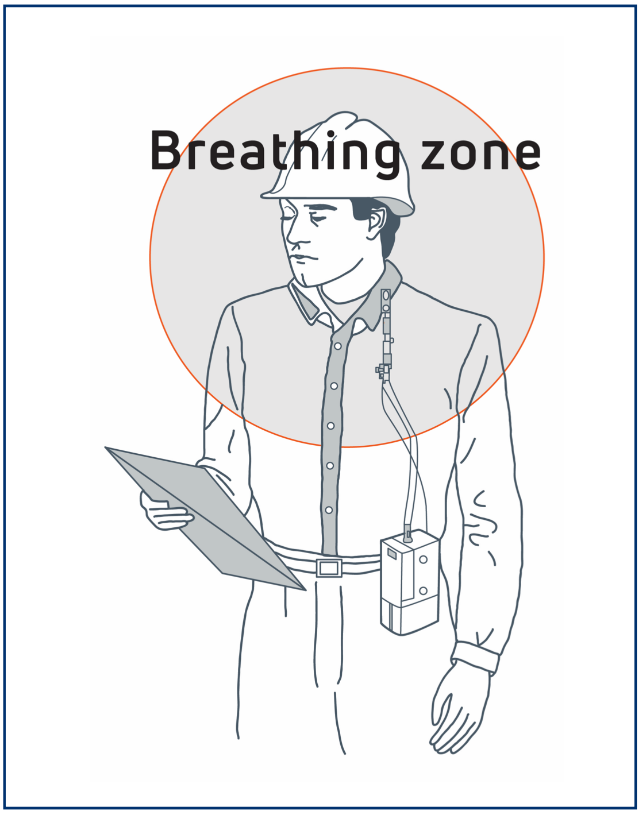

Figure 6: Breathing zone for personal exposure monitoring (Brown, 2004, p. 48)

To ensure validity of results for both personal and static monitoring, the measurement methodology must be validated for the intended purpose. Published methods undergo rigorous testing and validation to confirm that the intended airborne contaminant (such as a particular dust, fume or fibre) can be sampled and analysed according to the specific methodology, and that the results obtained can be interpreted correctly (e.g. personal monitoring results are compared to the relevant WES).

Routine surveys may be undertaken after completion of initial and measurement surveys. Routine surveys may be required at predetermined frequencies for purposes such as:

- Proactive assessment of effectiveness of controls at specific intervals
- Ongoing compliance monitoring to ensure exposures remain controlled
- Confirmation of compliance with statutory requirements as per regulatory authority requirements.

6.1.2 Measurement techniques

Measurement techniques commonly utilised include direct instrumentation and collection of samples for laboratory analysis.

Direct or *real-time instrumentation* utilises specialised equipment to provide instantaneous measurement information (i.e. a 'grab' sample that represents airborne concentrations at a point in time) or data that is logged and recorded over time (i.e. over one or more days). Due to the variety of instrumentation types available, it is important to understand the strengths and limitations of the equipment prior to use and ensure it is fit for purpose. The location of instrumentation must be carefully considered to ensure measurements are meaningful and meet the intention of the monitoring program. Results of direct instrumentation should not be compared to WES unless collected within the breathing zone of the operator over a representative period of time.

Airborne sampling, involving collection of samples for later analysis, is the most common method of determining airborne concentrations of DFF. Airborne collection equipment for DFF incorporates a special type of collection media known as a sample head to capture or 'filter' the airborne contaminant from the air. Air is drawn through the collection media via a sampling pump, and the media that has captured the airborne contaminant is analysed in a laboratory to determine the amount of material collected, from which the airborne concentration can be calculated. Concentration results are commonly reported in milligrams per cubic metre (mg/m^3).

Also, *biological* and/or *health monitoring* overseen by a registered medical practitioner or occupational physician may be conducted to determine whether workplace exposures are impacting the health of workers. Depending on the agent, testing methods can include physiological examination, testing of body functions (e.g. respiratory function) or collection of samples for testing (e.g. blood or urine). (See section 6.3.)

The intent of the sampling will determine the most appropriate strategy (i.e. personal or static monitoring) and the measurement technique. When unknown chemicals or concentrations are present, collection of a real-time 'grab' sample may be appropriate to establish the airborne concentration. Information obtained from laboratory analysis of airborne sampling can then be used to help inform future monitoring or immediate implementation of controls as required.

6.1.3 Validity and rigour in assessments

Apart from being undertaken by a competent person, such as a COH®, workplace measurements must:

- Use appropriate and validated methods; Australian Standard methods are preferred, however, validated methods from international sources may be used when local methods are not available
- Employ equipment (e.g. sampling pumps, flowmeters, direct reading instruments) that is fit for purpose and suitably calibrated; the National Association of Testing Authorities (NATA) and the Australian Institute of Occupational Hygienists (AIOH) provide information for calibration of sampling equipment used for airborne sampling of DFF[37]
- Ensure analysis of workplace samples is conducted by a NATA accredited laboratory facility or by the appropriate regulatory authority to carry out the specific analysis
- Ensure sampling is representative of exposure/task:
    - Samples are best collected across the majority of a worker's normal shift
    - Individuals sampled must be selected to ensure coverage of all impacted work groups; this requires an understanding of the similar exposure groups (SEGs) present in a workplace and the number of samples required to be collected for each SEG
- Establish defined criteria against which results can be compared taking account of:
    - *Workplace Exposure Standards for Airborne Contaminants* (SWA, 2019) and *Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants* (SWA, 2013)[38]
    - Specific industry or best practice guidance.

It is essential that a formal report is issued for the risk assessment. It is recommended that reports follow the AIOH occupational hygiene report writing guidelines (AIOH, 2017) and include:

- Executive summary
- Aim and purpose of the sampling, including who undertook the site work
- Process description
- Methodology, equipment and analysis techniques
- Sampling data and calculated results (usually in a table format) and applicable WES values
- Incorporation of appropriate statistical analysis and parameters for results to assist interpretation
- Conclusions and recommendations based on the results, incorporating application of the hierarchy of control measures to the specific workplace context

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[37] See NATA (www.nata.com.au/) and AIOH (www.aioh.org.au)

[38] Use of international exposure standards requires caution and must be supported by relevant justification.

- Analytical reports (i.e. NATA-endorsed certificates of analysis).

6.2 Air monitoring

This section reviews specific DFF air monitoring strategies, with reference to some relevant standards and guidance material.

6.2.1 Dust

Airborne dust can be created during mechanical processes which create smaller particles from solid materials such as rocks or timber; or when powdered and crushed materials are handled or transferred. Settled dust may also become re-airborne if disturbed and exposure may occur.

The methodology, sampling equipment and analysis techniques must be appropriate for the size and toxicity of the dust. Commonly used Australian Standard methods are:

- *AS 3640–2009 Workplace Atmospheres – Method for Sampling and Gravimetric Determination of Inhalable Dust* (SA, 2009a)
- *AS 2985–2009 Workplace Atmospheres – Method for Sampling and Gravimetric Determination of Respirable Dust* (SA, 2009b).

Sample analysis normally incorporates gravimetric analysis (for respirable or inhalable dust) with secondary analysis conducted as required using techniques such as X-ray fluorescence spectrometry, X-ray diffraction or infrared analysis (e.g. for various elements, α-quartz or cristobalite).

When undertaking risk assessments for airborne dust, explosion potential must be considered, and a specialist professional may be required to assist. When certain types of airborne dust are present (e.g. flour, coal, metal and sugar dust) under specific conditions (including airborne concentration and presence of ignition source), they can explode and catch fire.[39]

6.2.2 Fumes

While the particle size of fume is generally <0.1 µm, the sampling methods utilise inhalable dust sampling techniques. Sampling should be conducted in accordance with:

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[39] See *OHS BoK* 17.4 Process Hazards (Chemical) for a discussion of dust explosions.

- *AS 3640–2009 Workplace Atmospheres – Method for Sampling and Gravimetric Determination of Inhalable Dust* (SA, 2009a)
- *AS 3853.1–2006 Health and Safety in Welding and Allied Processes – Sampling of Airborne Particles and Gases in the Operator's Breathing Zone. Part 1: Sampling of Airborne Particles* (SA, 2006).

Analysis of the samples normally combines gravimetric analysis (to determine the overall amount of welding fume) with secondary analysis conducted as required depending on the elements expected in the welding fume, which arise from the type of metal being welded, consumables used and type of welding equipment (e.g. metal inert gas, MIG; tungsten inert gas, TIG).[40]

6.2.3 Fibres

Fibres that can impact the respiratory system are known as respirable fibres. Different sampling methodologies and equipment are required depending on the fibre type and size. The most common type of fibres sampled in Australia are respirable asbestos fibres. Others include MMVF, raw cotton fibres, and composite fibres such as Kevlar® fibres.

When determining whether sampling of airborne respirable asbestos fibres is required, it is essential to take account of *How to Safely Remove Asbestos: Code of Practice* (SWA, 2020c), any regulatory requirements for the specific jurisdiction and situation-specific expert advice. Special conditions can exist for persons who carry out the monitoring (e.g. independent licensed asbestos assessors), with specific reporting requirements (SWA, 2020c).[41]

Control monitoring (i.e. static sampling) is necessary during removal of all friable asbestos-containing material (ACM) (SWA, 2020c), with the sampling equipment positioned in strategic locations such as outside the removal enclosures and in areas where decontamination units are located (NOHSC, 2005).[42] When non-friable ACM is being removed, the decision to undertake airborne fibre sampling should be based on a risk assessment; also, it may be conducted to provide confidence in the process and peace of mind for workers and community members. As noted in section 6.1, results obtained from static sampling cannot be compared to the WES. Exposure monitoring in a worker's

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[40] Information about welding can be found on the Australian Welding Institute website (www.welding.org.au/).

[41] See also *Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres* (NOHSC, 2005), which provides information on the sampling and analysis of respirable asbestos fibres.

[42] *Friable asbestos* is "Material that is in a powder form or that can be crumbled, pulverised or reduced to a powder by hand pressure when dry, and contains asbestos" and *non-friable asbestos* is "Material containing asbestos that is not friable asbestos, including material containing asbestos fibres reinforced with a bonding compound" (SWA, 2020c, pp. 69, 70).

breathing zone "should be carried out to determine a worker's exposure to airborne asbestos if there is uncertainty as to whether the exposure standard may be exceeded at the workplace" (SWA, 2020c, p. 29). Whilst this type of monitoring can be conducted in certain circumstances, it is not a requirement during tasks such as asbestos removals, therefore caution must be employed regarding the circumstances under which this form of sampling is undertaken.

When reviewing results obtained from airborne asbestos monitoring, the most common requirement is that results be <0.01 fibres/mL air (the detection limit of the method), which means that no airborne respirable asbestos fibres were detected in the air at the time and location that the sample was collected (NOHSC, 2005; SWA, 2020c). It is also important to note that as most sampling for airborne asbestos is for control monitoring purposes (i.e., static monitoring) that the results obtained are not compared to the WES for asbestos (SWA, 2013). For monitoring of other types of respirable fibres, it is important to check the relevant methods and sampling equipment required.

For further information about DFF air monitoring, see

- Safe Work Australia's *Workplace Exposure Standards for Airborne Contaminants* (SWA, 2019) and *Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants* (SWA, 2013)[43]
- Australian Institute of Occupational Hygienists publications, including *Occupational Hygiene Monitoring and Compliance Strategies* (AIOH, 2014), *Simplified Occupational Hygiene Risk Management Strategies* (AIOH, 2020), which are available via the AIOH website[44] along with various AIOH position papers on topics such as asbestos, MMVF, welding fume, respirable crystalline silica, dusts not otherwise classified, coal dust and diesel particulate; and technical papers on sampling and analytical equipment (e.g. pumps, flowmeters) and calibration requirements.

6.3 Health monitoring

Regular health monitoring is referred to as a 'health monitoring program' (SWA, 2020a). A health monitoring program is designed to evaluate the effect of chemical exposure from all routes of exposure – inhalation, skin and eye exposure, ingestion and injection – and may consist of biological, biochemical or biological effect monitoring, as well as specific tests to determine the health status of the worker and extent of disease (Manno et al., 2010). Health

[43] It is important to check current WES values in the Hazardous Chemical Information System at www.hcis.safeworkaustralia.gov.au/

[44] www.aioh.org.au/education/publications/

monitoring may be proactive (i.e. before the worker develops symptoms or irreversible damage) or reactive. It should not take the place of implementing effective control measures according to the hierarchy of control. Health monitoring is usually overseen by a registered medical practitioner or occupational physician.

The type and frequency of health monitoring depends on a number of factors, including:

- Regulatory requirements
- Nature and type of chemical(s)
- Level and duration of exposure and route of entry
- Effectiveness of controls (SWA, 2020a).

There are ethical and confidentiality issues that need to be addressed prior to implementing a health monitoring program including:

- Informed consent from participants
- Samples only analysed for the contaminant that they were collected for
- Individual results treated as medical data and kept confidential between the OHS/health professional and the participant
- Collection of samples should not pose a risk to the health of the participant and the risk of invasive methods should be justified by the benefits of the program
- The health of those obtaining and handling bodily fluids must be protected (Manno et al., 2010).

The *Health Monitoring Guide for Persons Conducting a Business or Undertaking* (SWA, 2020a) outlines what health monitoring is, when it must be undertaken, and the process it must follow, including consultation and reporting. It is recommended that generalist OHS professionals seek guidance from an occupational health specialist in designing the program and interpreting the results.

Figure 7 depicts the health monitoring strategies employed to assess occupational exposure in the exposure-to-disease sequence. These are explained below.

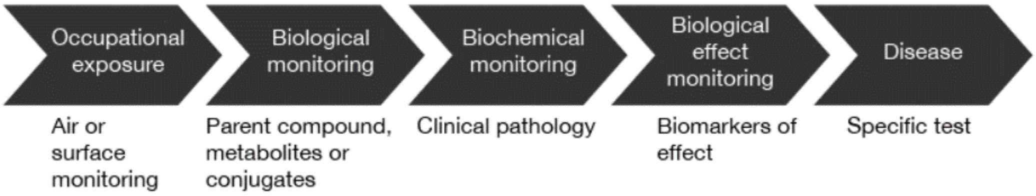

Figure 7: Pathway of occupational exposure to chemicals and health monitoring strategies employed (O'Donnell & Mazereeuw, 2020, p. 285)

Air or surface monitoring
Sections 6.1 and 6.2 outline the types of monitoring that should be undertaken.

Biological monitoring
Direct biological monitoring may be used to assess the internal dose of a chemical and thus determine the health risk from all routes of exposure. It may be undertaken by direct analysis of the contaminant (e.g. lead in blood or cadmium in urine) or by analysis of metabolites such as arsenic (inorganic and methylated metabolites in urine). Common sample matrices include urine, blood, exhaled air, oral fluid, hair and nails. With some matrices (e.g. urine), it is important to consider specific gravity or creatinine levels of the samples and apply creatinine corrections when required (Greim & Lehnert, 1998; Hertel et al., 2018). For biological determinants where concentration depends on the urine output, concentration levels are corrected and expressed relative to creatinine concentration (ACGIH, 2021). It is essential to understand the agent or biomarker half-life, which can vary from a few hours to months or even years, as this will inform the sampling strategy (Manno et al., 2010).

Prior to commencing biological monitoring, it is important to understand the toxicology of the chemical and how it is absorbed, metabolised, stored and excreted and any interferences for the selected method.[45] The choice of indicator and sampling time are critical in ensuring a reliable result (Manno et al., 2010). Depending on the half-life of the chemical, sample collection may be at the end of the shift, the next morning, the end of the work week or random. Specialised sample collection, storage and transportation may be required and a NATA-accredited laboratory should be consulted in the planning phase.

[45] See *OHS BoK* 17.2 Health Impacts of Chemical Hazards (in development at time of writing).

Although no biological exposure limits are listed by Safe Work Australia, international bodies such as the ACGIH have recommended biological exposure indices (BEIs®) that can be used for health risk evaluation for healthy workers in a similar fashion as WES can be used for airborne hazards. These do not constitute a line between safe and unsafe exposure and a number of samples may be required to draw any conclusions. Some processes have health monitoring guidelines, prescribed testing frequencies and biological reference values for the presence of the contaminant in the biological matrix (e.g. blood lead levels for lead work) (SWA, 2020b).

Biological monitoring is prone to interferences that may be difficult to differentiate from workplace exposures. Non-occupational exposures (e.g. welding at home, making lead sinkers, illicit drug use) or dietary sources (e.g. mercury in seafood) may obfuscate results, and a reference level compared to the general population can be important in determining the source of exposure (Manno et al., 2010).

Biochemical monitoring

While direct biological monitoring can be effective in determining the internal dose of a chemical, it does not consider the body's response to the exposure. Biochemical monitoring may include general health-based monitoring such as liver function tests (e.g. solvent exposure) and the analysis of zinc protoporphyrin in blood for lead exposure.

Biological effect monitoring

Biological effect monitoring is aimed at evaluating biomarkers that provide an early warning of overexposure to chemicals that, if not controlled, may lead to an irreversible effect. For example, the Australian aluminum industry was successful in significantly reducing the incidence of potroom asthma through the control of exposures and early evaluation of biological effect via histamine challenge testing to identify susceptible workers (Donoghue et al., 2011).

Spirometry, X-ray and high-resolution computed tomography (HRCT) are used for health surveillance of workers exposed to respirable crystalline silica; however, these methods are often unable to detect silicosis at the early stage (Austin et al., 2021). For early detection of silicosis, effort is being focused on developing validated non-invasive biomarkers such as exhaled breath condensate (EBC) (Austin et al., 2021).

Disease

The final step on the pathway of occupational exposure to chemicals is disease, which, if not irreversible, may still be halted or slowed with timely intervention. For example, the routine measurement of lung function (e.g. as an indication of pneumoconiosis) is mandated in the

WHS Regulations (SWA, 2022) and state mining regulations.[46] Other more invasive or higher-risk tests such as chest X-rays and CT scans (e.g. asbestosis, silicosis) and biopsies may be used for more definitive diagnosis and workers' compensation purposes. Non-invasive methods such as cell-free DNA (cfDNA) to detect and characterise lung cancer are in development and will reduce the risk involved in performing them when weighed against the benefit of these tests (Mathios et al., 2021).

7 Prevention and control

Creating and maintaining a safe and healthy workplace is a dynamic process that does not happen by chance. It requires a systematic approach to continuously improve the working conditions and reduce exposures to DFF. Effective prevention and control begin with a commitment to work health and safety from all stakeholders (SWA, 2018b). Management commitment is essential to demonstrate that work health and safety is integrated into the management system and implemented from the highest levels within the organisation.[47] Consultation is a legal requirement and an essential part of managing health and safety risks that enables stakeholders to participate and share information about their work health and safety. Using the knowledge and experience of everyone helps to identify safety hazards and risks and to find and communicate practical solutions (SWA, 2018b).

The risk management process is outlined in the *How to Manage Work Health and Safety Risks: Code of Practice* (SWA, 2018b), which states "the most important step in managing risks involves eliminating them so far as is reasonably practicable, or if that is not reasonably practicable, minimising the risks so far as is reasonably practicable" (p. 18).[48] The general principles of hazard control described in *OHS BoK* 34.1 Prevention and Intervention and *OHS BoK* 17.1 Management of Hazardous Chemicals also apply to DFF. Controls directly benefit workers by removing or reducing exposure to provide a safer and healthier workplace. Businesses also benefit by complying with legal requirements to protect workers and reduce future potential legal and compensation costs.

The *hierarchy of control measures* is an established framework that has long been used by OHS professionals. Figure 8 describes the framework as it applies to airborne contaminants. The *How to Manage Work Health and Safety Risks: Code of Practice* (SWA, 2018b) provides information supporting the use of the hierarchy of control measures in workplaces and depicts the controls in order of most-to-least effective and protective (i.e. elimination,

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[46] See https://www.safeworkaustralia.gov.au/safety-topic/industry-and-business/mining

[47] See *OHS BOK* 12.2 OHS Management Systems.

[48] See also *OHS BoK* 31 Risk.

substitution, isolation and engineering, administrative and personal protective equipment).[49] Often a combination of controls will be required to control risks so far as is reasonably practicable (SWA, 2018b).

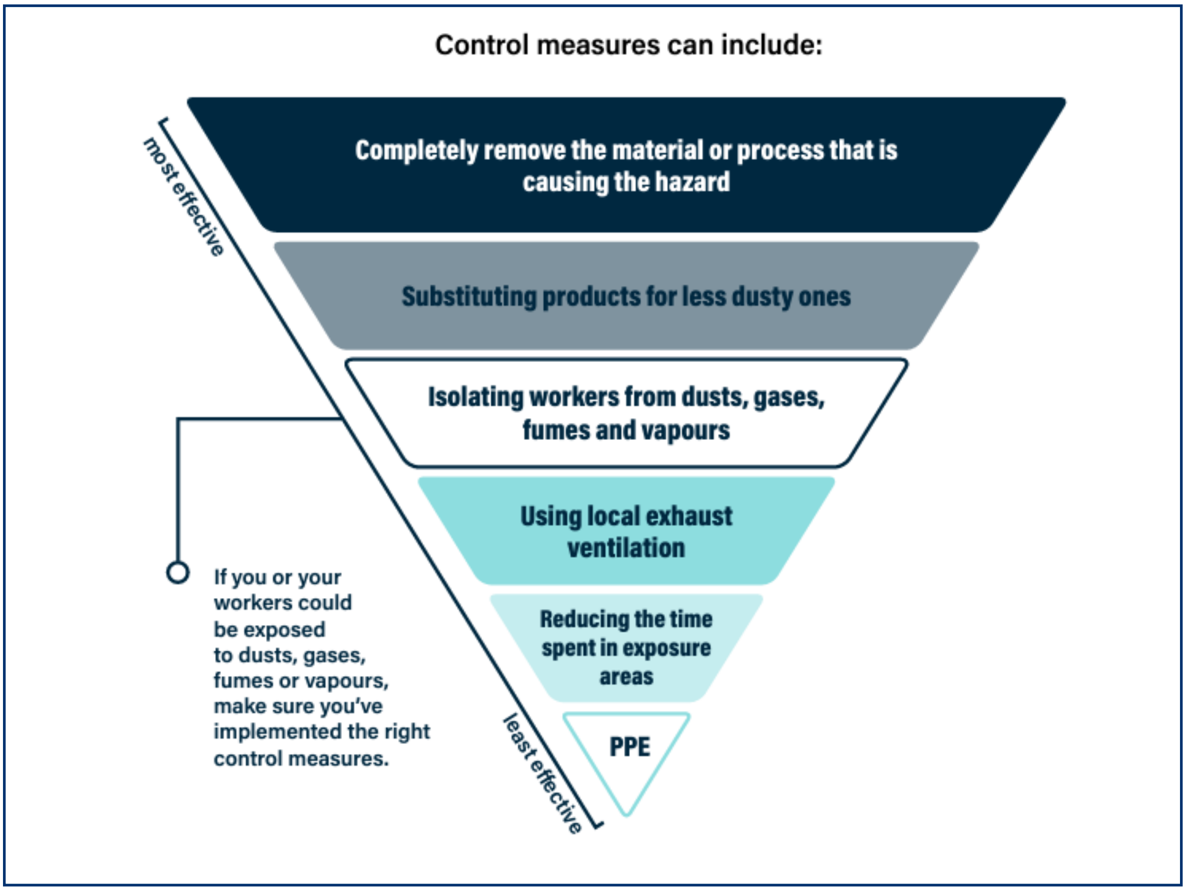

Figure 8: Hierarchy of control measures for airborne contaminants (SWA, 2021b)

Equally important as selecting control measures is determining where on the exposure pathway controls are most applicable.

Controls are usually placed:

1. At the source (where the hazard "comes from")
2. Along the path (where the hazard travels)
3. At the worker (CCOHS, 2022; Figure 8).

The most effective application of controls is at the source, with effectiveness diminishing further along the exposure pathway. It may be necessary to apply a different control, or a

[49] See also *OHS BoK* 34 1 Prevention and Intervention.

combination of controls, at each point in the pathway to achieve an acceptable reduction in risk.

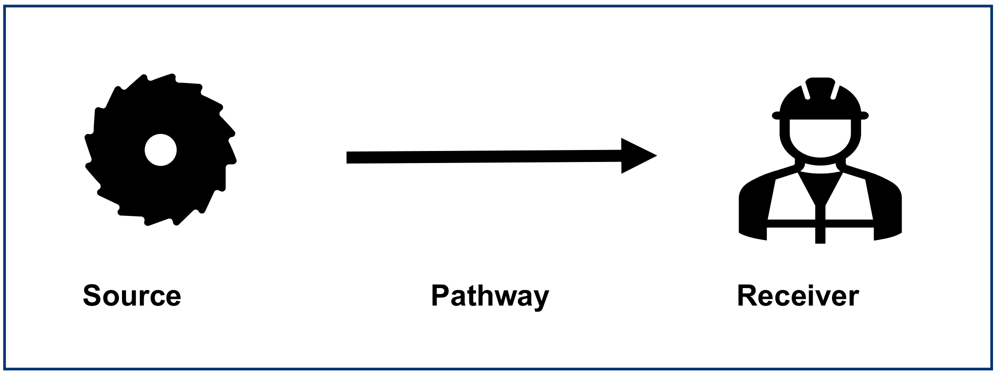

Figure 9: Controlling risk at the source, pathway and receiver

A systems approach[50] to prevention and control of worker exposure to DFF requires:

- Ensuring there is input from a range of relevant people (e.g. workers, subject matter experts, engineers), depending on the process and risk
- Understanding regulatory requirements and industry codes of practice for the specific contaminant or process
- Investigating available and suitable controls
- Knowing how much control is needed to reduce exposure to acceptable levels
- Implementing controls as early as possible in the process; planning in the design phase is best
- Knowing there is no point continuing to monitor hazards if controls are not implemented
- Recording information about the use and management of controls in a management system for audit purposes and future reference, particularly when there are changes to workplace personnel.

As advised by the code of practice, during the investigation of appropriate controls, consideration must be given to ensuring the proposed control does not introduce new hazards; "If this is not possible, any new hazards or risks introduced will need to be managed" (SWA, 2018b, p. 21). For example, a product may be substituted with a less hazardous one, still requiring an engineering control such as ventilation, as well as

[50] See *OHS BoK* 12.1 Systems and Systems Thinking.

administrative controls such as maintenance systems and training, and personal protective equipment.

If implemented correctly, maintained properly and embedded into operating procedures and workplace culture, controls will reduce worker exposure. However, continuous monitoring and improvement is necessary. It is important to verify the effectiveness of controls and determine whether they are working as planned, or whether a more effective control can be applied (SWA, 2018b). Figure 10 shows the plan-do-check-act (PDCA) cycle where the aim is for continuous and better-quality improvement over time. Developed during the 1950s, the PDCA cycle "emphasized the prevention of error recurrence by establishing standards [or exposure controls] and the ongoing modification of those standards" (Moen & Norman, 2009, p. 7). At each improvement of the standard, the process is assessed, with further improvement planned, made, enacted and checked for desired outcome.

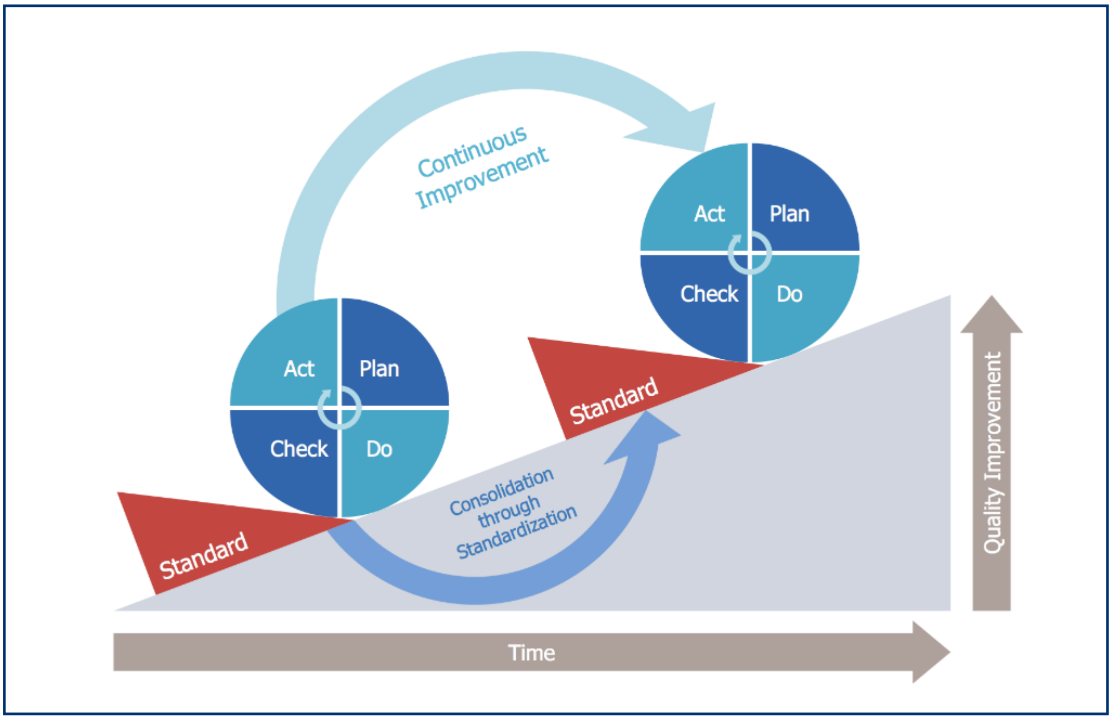

Figure 10: Plan-do-check-act cycle (ConceptDraw.com, n.d.)

7.1 DFF risk control resources

Examples of strategies and resources to assist DFF risk control are listed below.

- *Control banding* is a simplified method of determining controls.

  > Control banding is a process used in some countries where a hazardous chemical is assigned to a band, based on the chemical's hazard classification and use. Each band may have a different control solution, for example: band 1 – good industrial hygiene practice, band 2 – use local exhaust ventilation, band 3 – enclose the process. (SWA, 2020d, p. 22)

  Control banding is particularly useful where there are no exposure standards, and where sampling has not been done to determine worker exposure level. Developed to assist small-to-medium businesses that do not usually have access to risk assessment expertise, it provides an easy to understand, practical approach to controlling hazardous exposures. It should not take the place of quantitative workplace exposure monitoring and evaluation. There are several formats of control banding available, including COSHH Essentials,[51] the International Chemical Control Toolkit (ILO, 2006) and Stoffenmanager (The Netherlands).[52]
- *Breathe Freely Australia*, an initiative of the AIOH in conjunction with the British Occupational Hygiene Society, provides practical resources aimed at reducing occupational lung disease in construction, welding, engineered stone, mining and quarrying.[53]
- *Safe Work Australia* provides information and resources for controlling exposures to DFF, including the 'Clean Air. Clear Lungs.' national campaign.[54]
- *OHS regulators.* Each state and territory has its own regulating body that provides advice to businesses on work health and safety. Their respective websites may provide insight into controls for the specific hazards of businesses in their jurisdiction.[55]
- *Mining resources*, e.g.
  - Queensland – *Recognised Standard 15: Underground Respirable Dust Control* (DNRME, 2017); *Recognised Standard 20: Dust Control in Surface Mines* (DNRME, 2019); *QGL02 Guideline for Management of Respirable Dust in Queensland Mineral Mines and Quarries* (DNRME, 2020)

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[51] Garrod et al. (2007) explained the development and approach of COSHH Essentials, which provides basic advice in a series of industry-specific and generic 'control guidance sheets.' Published by the UK Health and Safety Executive, COSHH Essentials is available at www.hse.gov.uk/coshh/essentials/index.htm

[52] Developed by Cosanta BV, Stoffenmanager is available at www.stoffenmanager.com/

[53] See www.breathefreelyaustralia.org.au

[54] See www.safeworkaustralia.gov.au/clearlungs

[55] See www.safeworkaustralia.gov.au/law-and-regulation/whs-regulators-and-workers-compensation-authorities-contact-information/role-whs-regulators

    - New South Wales – *Guideline for the Management of Diesel Engine Pollutants in Underground Environments: MDG 29* (NSWDPI, 2008); the NSW coal industry Standing Dust Committee[56]
    - Western Australia – *Preparation of a Health and Hygiene Management Plan – Guide* (DMIRS, 2018); *Management of Fibrous Minerals in Western Australian Mining Operations: Guideline* (DMP, 2015).
- *Welding resources*, e.g.
    - *Welding Processes: Code of Practice* (SWA, 2021d)
    - *The 2022 Practical Guide to Welding Fume Control* (AWS, 2022)[57] provides guidance to control exposure utilising hierarchy of control measures.

7.2 DFF controls

Table 4 lists some examples of generic DFF controls for each level of the hierarchy of control measures.

Table 4: Generic controls for dusts, fumes and fibres[58]

Control examples	Comment
Elimination	
Prohibition of any new use or reuse (asbestos)	• New asbestos products cannot be used • Asbestos that has been removed to repair something, cannot be put back into place
Eliminate at the source (e.g. silica dust)	• Eliminate processes that generate DFF or treat at the point of generation or on the transmission path
Substitution	
Pellets, granules or flakes instead of powder	• Pellets, granules or flakes are less likely to break down enough to become airborne
Slurry or wet process instead of a dry product	• Slurries and wet processes do not let particles become airborne, unless they are spilt and dry out • Wet methods for e.g. silica-containing products should be used in combination with properly designed water suppression and local exhaust ventilation
Glass, rock and glass wool (MMVF) instead of asbestos	• MMVF are not as toxic and designed to be biosoluble in lung tissue
Marble, granite, timber, stainless steel or laminate instead of engineered stone for benchtops	• Low concentrations or no crystalline silica with reduced hazards

[56] See www.coalservices.com.au/mining/workplace-safety-and-compliance/industry-working-groups/standing-dust-committee

[57] See the Australian Welding Supplies (AWS) website at www.awsi.com.au

[58] Sources: HSE (2017), SWA (2018b, 2022a).

Control examples	Comment
Engineering (including isolation and segregation)	
Isolate or contain dusty operations with operators on the outside of the enclosure	• Sandblasting or glove box cabinets for abrasive blasting to remove rust, paint stains and other impairments to objects
Segregate hazardous processes or operations by keeping operators away	• Placing hazardous processes away from other processes in a separate room or dedicated building can minimise the number of workers at risk and reduce secondary contact for unsuspecting workers
Decrease height of free-falling powders	• Reducing the height reduces the billowing effect the dust has when it hits a surface and the flow of entrained air, which otherwise carries dust
High-efficiency particulate air (HEPA) vacuum instead of sweeping	• Sweeping gathers the large particles but re-entrains into the air the smaller particles, which can stay airborne for long periods of time (hours to days) and will eventually resettle onto surfaces • If household-grade vacuums are used, small particles flow through the system and are dispersed back into the air, allowing secondary exposure • There are several classes of HEPA filters; research the correct filter to use, and ensure it features the Australian standard logo as per AS 4260–1997 (SA, 1997) and AS/NZS 60335.2.69:2017 (SA/SNZ, 2017) • The vacuum, which must display the high-hazard (H) class symbol below, requires specific and regular maintenance, inspection and testing (WorkSafe Queensland, 2017) 
Air-conditioning filters in vehicles, offices, crib rooms, etc.	• Filters are designed to filter out specific size fractions and contaminants • Ensure the correct filter is used for the workplace contaminant(s) and that it is regularly and properly maintained

Water/chemical dust suppression	• Keeps products wet to minimise dust generation
	• Two main forms:
	  ○ Dust suppression of stockpiles can utilise water cannons or stockpile sprays; the water can be mixed with other products to form a crust or layer to reduce drying out through evaporation and to extend the longevity of the suppression
	  ○ Airborne dust suppression is used to reduce already-airborne dust particles, often at the source or where dusty materials are transferred such as conveyor belts or transfer points
	• Extreme care needs to be taken in regard to droplet size, nozzle design, pressure and quality of water delivered; if these are not adequately considered, dust will not be well controlled, the area can become too wet or the system may not work at all

Ventilation – local exhaust ventilation (LEV)	• Generally, dilution ventilation is not suited to DFF as it spreads the contaminant through the workplace, diluting it as it goes • LEV is required at the source of contaminant generation; it works by extracting clouds of contaminants before people breath them in

Control examples	Comment
	• To determine the correct type of LEV, it is imperative to know the type of contaminant and how it is generated from the source • LEV systems must be individually designed for the specific process and contaminant
Automation and/or remote control	• Automated welding processes for continuous operations • Remote control operations such as in longwall mining where operators work from the surface of the mine away from dust
Administrative	
Maintenance of filter systems, blades, ventilation systems	• Generally, any physical control strategy will need maintenance over time • If the control is an engineering control, then moving parts are likely to have been introduced and regular inspection and maintenance will be required to ensure it continues to operate as expected
Worker training and education in workplace hazards, how to operate implemented controls and what to do if controls don't appear to be working effectively	• Workers need to be continually trained, retrained and updated regarding the hazards in the workplace and the ongoing use of control • Utilising controls and working in a manner that reduces exposure may not be part of workers' core work, and thus may not be at the forefront of their minds
Reduce exposure duration for workers	• Roster workers into different areas (job/shift rotation) to reduce the amount of time they are exposed to a contaminant
Policy, procedures, job safety analyses (JSAs), safe work method statements (SWMSs)	• All controls should be included in site WHS systems; the location and level of detail will depend on individual businesses
Personal Protective Equipment	
Implement a full respiratory protective equipment (RPE) program, including fit testing of equipment	• This is particularly important for DFF • AS/NZS 1716:2012 (SA/SNZ, 2012) outlines types of respiratory devices and AS/NZS 1715:2009 (SA/SNZ, 2009) provides detail on respiratory protection programs, selecting the correct RPE and outlines limitations; businesses using RPE must satisfy these requirements • Consider whether a P1 (mechanically generated particles) or P2 (mechanically and thermally generated particles) respirator is required
Selection, provision and maintenance of PPE	• All PPE must meet the relevant standard for the application for which it is being used • A complete PPE management program is required, including selection, provision, maintenance and worker training in use and correct wearing • Further information can be found in the relevant Australian Standard
Particle/pre-filter on respiratory equipment	• For respiratory devices used to remove particulates, it is important that a particulate filter is in place; it may be replaceable or an integral part of the respirator construction • It is important to understand what type of filter is present and whether it requires a separate particulate filter • Gas and vapour filters do not have a particulate filter integrated into the filtration media; a combination filter may be required
Gloves for exposure to fibreglass to reduce skin	• Seek advice from glove suppliers, particularly when dealing with a combination of chemicals, particles and physical actions

Control examples	Comment
irritation and protect against abrasion, etc.	

Following the implementation of controls, a review of worker exposure should be conducted to ensure exposures have reduced as expected (SWA, 2018b; section 6). Ongoing assessments should occur to ensure implemented controls remain effective and to determine if further controls can be considered and introduced. Consistent with the PDCA cycle (Figure 10), controls should be continuously evaluated with a view to maintaining and improving their effectiveness.

7.3 Case study

The following case study demonstrates the importance of the continuous improvement process (Figure 10). Although several controls were already in place, phases of improvement were required to ensure worker protection.

Unloading zinc and copper concentrate

A workplace that usually unloads copper concentrate gained a new contract to unload zinc concentrate. Health effects from occupational exposure to copper dust can include

> …irritation of the skin, and the respiratory mucosae, with congestion of the nasal and mucous membranes and ulceration with perforation of the nasal septum. Fumes from the heating of metallic copper can cause metal fume fever, although concurrent exposure to other metals may contribute to symptoms (ILO, 2022, p. 235)

Health effects from zinc concentrate are more severe. Zinc concentrate contains not only zinc, but also lead, which can cause many health effects.

> Lead toxicity affects multiple organs [and] high occupational exposures typically cause anaemia, central nervous system effects, peripheral neuropathy, chronic kidney disease leading to secondary hypertension and cardiovascular disease (ILO, 2022, p. 64).

The task involved two people operating large forklifts to unload containers of zinc concentrate into a hopper. A third worker took a sample from each container after it had been unloaded (approximately every 8-10 minutes) and a fourth worker operated a front-end loader to move the unloaded zinc concentrate into a stockpile. Later, the zinc concentrate was loaded onto an enclosed conveyor for further distribution. The shift length varied between 8 and 12 hours depending on the number of containers to be unloaded. All unloading and loading work was completed within a large shed.

The zinc process was to occur intermittently and, although lead was present in the concentrate, it was deemed by the OHS regulator to not be a lead risk exposure task.

Prior to the zinc concentrate work, the site had several controls in place to reduce worker exposure to the copper concentrate.

Existing controls for copper concentrate

Engineering

- Enclosed air-conditioned cabins in the forklifts and loader
- A simple outdoor rest area with a sink, a chair and some weather coverage

Administration

- Job rotation

PPE

- P2 reusable respirator for the sampler

Phase 1:

Additional zinc concentrate controls

Engineering

- Introduction of a dry fog system for dust suppression
- Ongoing investigation into an automatic sampler as a longer-term control
- Provision of an improved location for the sampler to move to between samples (i.e. out of the dust and the weather) and an improved area for handwashing
- Provision of a change area

Administration

- Restriction of the number of people entering the shed, and ensuring short term visitors to the shed wore appropriate respiratory protection
- Review of maintenance of the air-conditioning filter system within the mobile equipment (at the time of sampling the schedule and type of filtering system was not known)
- Regular checks of the door seals of the mobile equipment
- Regular cleaning of mobile equipment using a HEPA vacuum to remove dust
- Worker education program via internal toolbox talks and visiting external experts regarding dust and exposure, health effects, how to reduce exposure, and awareness of secondary exposure to dust within a cabin and during clean-up
- Boot cleaning prior to cabin entry
- Implementation of a health surveillance program for blood lead levels (even though not deemed a lead risk job)
- Update of the WHS management system including JSAs to incorporate the new controls and changes to the process

PPE

- Coveralls worn over work clothing, which was laundered on site using a dedicated washing machine
- Fit testing and implementation of compliant PPE

Two phases of further controls were implemented to reduce worker exposure for both tasks, with a focus on the zinc concentrate task.

As part of an integrated review, the site engaged an occupational hygienist to determine if their controls for dust were adequate to protect the health of workers. Sampling demonstrated that the task that provided airborne concentrations over the exposure standard was the clean-up process where one worker used a shovel and a second worker operated a bobcat to clean the surfaces of the shed so it could be used again for the copper concentrate.

Although many excellent controls were in place, several additional controls were implemented in Phase 2.

Phase 2:

Additional zinc concentrate controls

Engineering

- Relocation of the change area to be further away from the dust

Administration

- Lead check tests conducted to ensure areas such as crib rooms were clean and lead free
- Review of, and subsequent changes to, the way the stockpile area was cleaned up
- Addition of the bobcat to the filter- and seal-maintenance checklist

Blood lead level results were below acceptable levels with the exception of one worker, who was observed to not wear their respirator unless reminded, to not wash their hands prior to eating, and to show general disregard for the controls. Also, he had a weekend hobby of making lead sinkers. This worker required further education and management as the controls were clearly adequate for most workers.

8 Emerging issues

As new chemicals and processes are invented, and even with existing materials and processes, new hazards may present themselves as emerging issues requiring risk assessment (SWA, 2018b). It is often only as a result of worker illness or disease within an industry or worker cohort that the identity and impact of the new hazard becomes evident.

This is the case with the resurgence of accelerated silicosis due to exposure to respirable crystalline silica seen in those working with engineered stone (section 2). A related example is when additional toxicological evidence is gathered on existing hazards such as crystalline silica. In recent years more information is has become available regarding the formation of reactive radical species on freshly fractured surfaces of crystalline silica particles, which can lead to increased cytotoxicity of quartz particles when they enter the lungs (AIOH, 2016). This information has an impact for industries that process materials containing crystalline silica (i.e. quartz) and control strategies utilised to protect workers in those workplaces.

Other examples of emerging hazards in the workplace include more widespread use of engineered nanoparticles,; new therapeutic formulations used in pharmaceuticals; and the invention of other man-made organic fibres such as those derived from plastics, which are used to manufacture fabrics and create flock- lined items such as display boxes.

The lessons to be learned include that new hazards and updated information can emerge at any time, thus it is important for OHS professionals to keep up to date with the latest technologies and associated health-related information. When limited toxicological or epidemiological data is available, including where there are no exposure standards, it is essential to apply a precautionary approach to ensure worker exposures are controlled. When conducting risk assessments and implementing controls in such circumstances, application of control banding or structured control strategies may be applicable.

9 Implications for OHS practice

Identifying risks and developing controls for the management of DFF is a specialised area requiring an understanding of chemistry, biology and toxicology. While this chapter provides some background information for generalist OHS professionals, it will not make them experts in this area. There will continue to be a need for a collaborative approach with allied professionals such as engineers, occupational hygienists and occupational physicians.

> Occupational hygienists use science and technology to measure worker exposures, assess worker risks and develop controls to improve the workplace environment. [They] can provide advice on control strategies including hazard elimination, engineering modifications, administrative controls and finally personal protective equipment. [They] focus on worker health protection by assessing the risk of hazards and improving work conditions and work practices. (AIOH, 2022)

> Occupational medicine takes a preventative approach to health and safety in the workplace by looking at how a work environment can affect a person's health, and how a person's health can affect their work…Occupational and Environmental Physicians (OEPs) provide specialist knowledge to ensure a healthy, productive workforce and connect a workplace with the diverse range of health services necessary to optimise the health and wellbeing of employees. (RACP, 2020)

The role of the generalist OHS professional is to recognise the hazards associated with DFF and the magnitude of possible consequences, to apply known controls and to engage experts before injuries and diseases occur. OHS professionals provide the trigger for action, ensuring that appropriate and timely action occurs to eliminate the hazards or minimise the risks. When limited toxicological or epidemiological data is available, including when there are no exposure standards, it is essential to take a precautionary approach to ensure worker exposures are controlled.

Comparisons could be made between this chapter and *OHS BoK* 13 Managing Process Safety, which also refers to a requirement for specialist interventions. Both chapters provide a knowledge base to facilitate engagement between OHS professionals and other experts so that collectively they can develop practical and safe workplace solutions. Some specific recommendations for how OHS professionals can support and facilitate this engagement are listed below.

Knowledge development

- Review *OHS BoK* chapters 7 The Human as a Biological System, 17.1 Management of Chemical Hazards, 17.2 Health Impacts of Chemical Hazards, 17.4 Process Hazards (Chemical) and 18 Biological Hazards to identify possible workplace hazards and how they may impact workers
- Ensure systems are developed and monitored to manage exposure to DFF consistent with other hazards in the workplace
- Keep up to date with emerging hazards (e.g. more widespread use of engineered nanoparticles) and relevant information with respect to worker health
- Consider what further information is required that may not be addressed in this chapter (and seek a mentor and/or expert support).

Engagement

- Take the initiative in learning more about the DFF hazards in your organisation
- Join AIOH or seek an occupational hygiene mentor as a way of increasing knowledge and facilitating wider engagement; if there is no occupational hygienist on site or in the organisation seek networking opportunities to develop contacts
- Identify triggers to ensure you know when to call in a specialist
- Engage with operational personnel and others to ensure sufficient familiarisation with tasks and hazards to assist in developing the scope and brief for any consultant support
- Ensure the hazards of DFF are considered in risk assessments and business cases when changes occur to products or processes
- Apply risk management principles and tools as appropriate for chronic illnesses and diseases as well as acute injuries to enhance OHS practice.

10 Summary

The dusts, fumes and fibres generated in many workplaces can lead to occupational diseases. Generalist OHS professionals must adopt sound risk management practices to ensure that all reasonable controls are in place and operating effectively. It is essential that the fundamental occupational hygiene practices of recognition, evaluation and control are utilised to protect worker health.

This chapter describes how DFF can impact workers. It outlines methods of risk assessment, prevention and control that are key to reducing the impact that DFF continue to have on workers. The chapter will assist OHS professionals to develop their knowledge in this area, recognise their limitations, and to work with other experts such as occupational hygienists and engineers to achieve well-controlled workplaces where the risks are managed.

References

ACGIH (American Conference of Government Industrial Hygienists). (2021). *Guide to occupational exposure values*. ACGIH.

ACGIH (American Conference of Government Industrial Hygienists). (2022). *History.* Retrieved from https://www.acgih.org/about/about-us/history/

AIHW (Australian Institute of Health and Welfare). (2018). *Australian mesothelioma registry*. Retrieved from https://www.mesothelioma-australia.com/home/

AIOH (Australian Institute of Occupational Hygienists). (2014). *Occupational hygiene monitoring & compliance strategies*. Retrieved from https://www.aioh.org.au/product/monitoring-pdf/

AIOH (Australian Institute of Occupational Hygienists). (2016). *Adjustment of workplace exposure standards for extended work shifts: Position paper*. Retrieved from https://www.aioh.org.au/product/wes/

AIOH (Australian Institute of Occupational Hygienists). (2017). *Guidelines for writing occupational hygiene reports* (3rd ed.). Retrieved from https://www.aioh.org.au/product/oh-report/

AIOH (Australian Institute of Occupational Hygienists). (2020). *Simplified occupational hygiene risk management strategies* (2nd ed.). Retrieved from https://www.aioh.org.au/product/simplified-pdf/

AIOH (Australian Institute of Occupational Hygienists). (2022). *What is occupational hygiene?* Retrieved from https://www.aioh.org.au/about/oh/

Alif, S., Glass, D., Abramson, M., Hoy, R., & Sim, M. A. M. (2020). *Occupational lung diseases in Australia 2006–2019*. Safe Work Australia. Retrieved from https://www.safeworkaustralia.gov.au/doc/occupational-lung-diseases-australia-2006-2019

Apthorpe, L., & Hines, J. (2020). Aerosols. In S. Reed, D. Pisaniello & G. Benke (Eds), *Principles of occupational health & hygiene: An introduction* (3rd ed., pp. 153-206). Routledge.

Asbestos Safety and Eradication Agency. (2017). *National asbestos profile for Australia*. Australian Government. Retrieved from https://www.asbestossafety.gov.au/find-out-about-asbestos/asbestos-safety-information/brochures/national-asbestos-profile-australia

ATSDR (Agency for Toxic Substances and Disease Registry). (2012). *Toxicological profile for cadmium*. US Department of Health and Human Services. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf

Austin, E. K., James, C., & Tessier, J. (2021). Early detection methods for silicosis in Australia and internationally: A review of the literature. *International Journal of Environmental Research & Public Health*, *18*(15), 8123.

AWS (Australian Welding Supplies). (2022). *The 2022 practical guide to welding fume control.* Retrieved from https://www.awsi.com.au/welding-safety-white-papers#

Bakand, S., & Hayes, A. (2016). Toxicological considerations, toxicity assessment, and risk management of inhaled nanoparticles. *International Journal of Molecular Sciences*, *17*(6), 929.

Baron, P. A. (2016). Factors affecting aerosol sampling. In A. R. Andrews & P. F. O'Connor (Eds), *NIOSH manual of analytical methods (NMAM)* (5th ed., pp. AE-1-AE-35). US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Retrieved from https://www.cdc.gov/niosh/nmam/pdf/NMAM_5thEd_EBook-508-final.pdf

Beckett, W. S. (1999). Detecting respiratory tract responses to air pollutants. In D. L. Swift & W. M. Foster (Eds), *Air pollutants and the respiratory tract. (Lung biology in health and disease volume 128)* (pp.105-118). Marcel Dekker.

Berry, G., Reid, A., Aboagye-Sarfo, P., de Klerk, N. H., Olsen, N. J., Merler, E., Franklin, P., & Musk, A. W. (2012). Malignant mesotheliomas in former miners and millers of crocidolite at Wittenoom (Western Australia) after more than 50 years follow-up. *British Journal of Cancer*, *106*(5), 1016-1020.

Bohle, P., & Quinlan, M. (2000). *Managing occupational health and safety: A multidisciplinary approach*. Macmillan Education.

Borm, P. J. A., Robbins, D., Haubold, S., Kuhlbusch, T., Fissan, H., Donaldson, K., Schins, R., Stone, V., Kreyling, W., Lademann, J., Krutmann, J., Warheit, D., & Oberdorster, E. (2006). The potential risks of nanomaterials: A review carried out for ECETOC. *Particle & Fibre Toxicology*, *3*(1), 1-35.

Brandys, R. C., & Brandys, G. M. (2008). *Global occupational exposure limits for over 6,000 specific chemicals* (2nd ed.). Occupational & Environmental Health Consulting Services Inc.

Brown, M. (2004). *Where will it all go wrong?* SKC. Retrieved from https://www.skcltd.com/images/pdfs/IET_Sept_2004_Taking_Valid_Air_Samples_Article.pdf

Carvalho, T. C., Peters, J. I., & Williams III, R. O. (2011). Influence of particle size on regional lung deposition – what evidence is there? *International Journal of Pharmaceutics*, *406*(1-2), 1-10.

CCOHS (Canadian Centre for Occupational Health and Safety). (2022). *Hazard control.* Retrieved from https://www.ccohs.ca/oshanswers/hsprograms/hazard_control.html

Cherniack, M. G. (2021, September 2). Hawk's Nest tunnel disaster. *E-WV: The West Virginia Encyclopedia.* Retrieved from https://www.wvencyclopedia.org/articles/338

ConceptDraw.com. (n.d.). *Plan-do-check-act (PDCA): PDCA process*. Retrieved from https://www.conceptdraw.com/samples/management-plan-do-check-act

Darquenne, C. (2020). Deposition mechanisms. *Journal of Aerosol Medicine & Pulmonary Drug Delivery*, *33*(4), 181-185.

De Matteis, S., Heederik, D., Burdorf, A., Colosio, C., Cullinan, P., Henneberger, P. K., Olsson, A., Raynal, A., Rooijackers, J., Santonen, T., Sastre, J., Schlünssen, V., van Tongeren, M., & Sigsgaard, T. (2017). Current and new challenges in occupational lung diseases. *European Respiratory Review*, *26*(146), 1-15.

DMIRS (Department of Mines, Industry Regulation and Safety). (2018). *Preparation of a health and hygiene management plan – guide*. Government of Western Australia. Retrieved from https://www.dmp.wa.gov.au/Documents/Safety/MSH_G_HHMP.pdf

DMP (Department of Mines and Petroleum). (2015). *Management of fibrous minerals in Western Australian mining operations: Guideline* (2nd ed.). Government of Western Australia. Retrieved from https://www.dmp.wa.gov.au/Documents/Safety/MSH_G_ManagementOfFibrousMineralsInWaMiningOperations.pdf

DNRME (Department of Natural Resources, Mines and Energy). (2017). *Recognised standard 15: Underground respirable dust control, Coal Mining Safety and Health Act 1999*. Queensland Government. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0018/1242225/recognised-standard-15.pdf

DNRME (Department of Natural Resources, Mines and Energy). (2019). *Recognised Standard 20: Dust control in surface mines, Coal Mining Safety and Health Act 1999*. Queensland Government. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0005/1462685/recognised-standard-20-dust-control-surface-mines.pdf

DNRME (Department of Natural Resources, Mines and Energy). (2020). *QGL02 Guideline for management of respirable dust in Queensland mineral mines and quarries, Mining and Quarrying Safety and Health Act 1999*. Queensland Government. Retrieved from https://www.resources.qld.gov.au/__data/assets/pdf_file/0006/1263669/qgl02-guideline-mines-quarries.pdf

Donaldson K., Tran, L., & Borm, P.J.A., 2007. The toxicology of inhaled particles: Summing up an emerging conceptual framework. In: *Particle Toxicology*. Donaldson, K. and Borm (Eds). CRC Press, Boca Raton

Donoghue, A. M., Frisch, N., Ison, M., Walpole, G., Capil, R., Curl, C., Di Corleto, R., Hanna, B., Robson, R., & Viljoen, D. (2011). Occupational asthma in the aluminum smelters of Australia and New Zealand: 1991–2006. *American Journal of Industrial Medicine*, *54*(3), 224-231.

Driscoll, T. (2021a). *Deemed diseases in Australia*. Safe Work Australia. Retrieved from https://www.safeworkaustralia.gov.au/doc/revised-list-deemed-diseases-australia

Driscoll, T. (2021b). *SWA deemed diseases list: Recommendations for amendments to 2015 list. Final report.* Retrieved from https://www.safeworkaustralia.gov.au/doc/review-2015-deemed-diseases-australia-report

Du, Y., Xu, X., Chu, M., Guo, Y., & Wang, J. (2016). Air particulate matter and cardiovascular disease: The epidemiological, biomedical and clinical evidence. *Journal of Thoracic Disease*, *8*(1), E8-E19.

Eaton, DL & Gilbert, SG 2015, 'Principles of toxicology', in CD Klaassen & JB Watkins (eds), *Casarett & Doull's Essentials of Toxicology*, 3rd edn, McGraw-Hill Education, New York, pp. 5-20.

Firth, I., Golec, R., Di Corleto, R., Ng, K., & Wilson, J. (2020). *Simplified occupational hygiene risk management strategies* (2nd ed.). Australian Institute of Occupational Hygienists. Retrieved from https://www.aioh.org.au/product/simplified-pdf/

Flage, R., & Askeland, T. (2020). Assumptions in quantitative risk assessments: When explicit and when tacit? *Reliability engineering & System Safety*, *197*, 106799.

Franklin, P., Reid, A., Olsen, N., Peters, S., de Klerk, N., Brims, F., Threlfall, T., Murray, R., & Musk, A. (2016). Incidence of malignant mesothelioma in Aboriginal people in Western Australia. *Australian & New Zealand Journal of Public Health*, *40*(4), 383-387.

Garrod, A. N. I., Evans, P. G., & Davy, C. W. (2007). Risk management measures for chemicals: The "COSHH essentials" approach. *Journal of Exposure Science & Environmental Epidemiology*, *17*(1), S48-S54.

Golec, R. (2020). The concept of the exposure limit for workplace health hazards. In S. Reed, D. Pisaniello & G. Benke (Eds), *Principles of occupational health & hygiene: An introduction* (3rd ed., pp. 52-82). Routledge.

Gray, C., Carey, R. N., & Reid, A. (2016). Current and future risks of asbestos exposure in the Australian community. *International Journal of Occupational & Environmental Health*, *22*(4), 292-299.

Greim, H., & Lehnert, G. (1998). Creatinine as a parameter for the concentration of substances in urine. In H. Greim & G. Lehnert (Eds), *Biological exposure values for occupational toxicants and carcinogens: Critical data evaluation for BAT and UKA values* (vol. 3, pp. 35-44). Wiley-VCH.

Hayes, A., & Bakand, S. (2010). Inhalation toxicology. In A. Luch (Ed.), *Molecular, clinical and environmental toxicology. Volume 2: Clinical toxicology* (pp. 461-488). Springer.

Hendrick, DJ, Burge, PS, Beckett, WS, Ghurg, A & Harting, AM 2004, 'Occupational Disorders of the Lung: Recognition, Management, and Prevention', *AAOHN Journal*, vol. 52, no. 2, pp. 47-8.

Hertel, J., Rotter, M., Frenzel, S., Zacharias, H. U., Krumsiek, J., Rathkolb, B., de Angelis, M. H., Rabstein, S., Pallapies, D., & Brüning, T., Grabe, H. J., & Wang-Sattler, R. (2018). Dilution correction for dynamically influenced urinary analyte data. *Analytica Chimica Acta*, *1032*, 18-31.

Hoy, R., Burdon, J., Chen, L., Miles, S., Perret, J. L., Prasad, S., Radhakrishna, N., Rimmer, J., Sim, M. R., Yates, D., & Zosky, G. (2020). Work-related asthma: A position paper from the Thoracic Society of Australia and New Zealand and the National Asthma Council Australia. *Respirology*, *25*(11), 1183-1192.

HSE (Health and Safety Executive). (2017). *Controlling airborne contaminants at work: A guide to local exhaust ventilation (LEV)* (3rd ed.). TSO. Retrieved from https://www.hse.gov.uk/pubns/books/hsg258.htm

ILO (International Labour Organization). (2006). *International chemical control toolkit*. Retrieved from https://www.ilo.org/legacy/english/protection/safework/ctrl_banding/toolkit/icct/

ILO (International Labour Organization). (2022). *Diagnostic and exposure criteria for occupational diseases. Guidance notes for the diagnosis and prevention of the diseases in the ILO list of occupational diseases (revised 2010).* Retrieved from https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---lab_admin/documents/publication/wcms_836362.pdf

ISO (International Organization for Standardization). (1995). *ISO 7708:1995 Air quality – particle size fraction definitions for health-related sampling*. Retrieved from https://www.iso.org/standard/14534.html

ISO (International Organization for Standardization). (2018). *ISO 31000:2018 Risk management – guidelines*. Retrieved from https://www.iso.org/standard/65694.html

Kirkeleit, J., Riise, T., Bjørge, T., & Christiani, D. C. (2013). The healthy worker effect in cancer incidence studies. *American Journal of Epidemiology*, *177*(11), 1218-1224.

Klaassen, C. D., Watkins, J. B., & Acosta, D. (2015). … In C. D. Klaassen & J. B. Watkins III (Eds), *Casarett & Doull's essentials of toxicology* (3rd ed., pp. …). McGraw-Hill Education.

Klaunig, J. E. (2014). Chemical carcinogenesis. In S. M. Roberts, R. C. James & P. L. Williams (Eds), *Principles of toxicology: Environmental and industrial applications* (3rd ed.). John Wiley & Sons.

Leigh, J., & Driscoll, T. (2003). Malignant mesothelioma in Australia, 1945–2002. *International Journal of Occupational & Environmental Health*, *9*(3), 206-17.

Leikauf, G. D. (2019). Toxic responses of the respiratory system. In C. D. Klaassen (Ed.), *Casarett & Doull's toxicology: The basic science of poisons* (9th ed., pp. 793-837). McGraw-Hill.

Leung, J. M., Niikura, M., Yang, C. W. T., & Sin, D. D. (2020). Covid-19 and COPD. *European Respiratory Journal*, *56*(2), 1-9.

Liu, C., & Sun, Q. (2015). Pulmonotoxicity: Toxic effects in the lungs. In S. M. Roberts, R. C. James & P. L. Williams (Eds), *Principles of toxicology: Environmental and industrial applications* (3rd ed., pp. 179-195). John Wiley & Sons.

Lizarralde, S. M., Wake, B., Thompson, V., & Weisman, R. S. (2003). Jewelers. In M. I. Greenberg, R. J. Hamilton, S. D. Phillips & G. J. McCluskey (Eds), *Occupational, industrial, and environmental toxicology* (2nd ed., pp. 198-215). Mosby.

Manno, M., Viau, C., Cocker, J., Colosio, C., Lowry, L., Mutti, A., Nordberg, M., & Wang, S. (2010). Biomonitoring for occupational health risk assessment (BOHRA). *Toxicology Letters*, *192*(1), 3-16.

Mapel, D., & Coultas, D. (2002). Disorders due to minerals other than silica, coal, and asbestos, and to metals. In D. Hendrick, W. Beckett, P. S. Berge & A. Chung (Eds), *Occupational disorders of the lung: Recognition, management, and prevention* (pp. 163-190). Saunders.

Mathios, D., Johansen, J. S., Cristiano, S., Medina, J. E., Phallen, J., Larsen, K. R., Bruhm, D. C., Niknafs, N., Ferreira, L., Adleff, V., Chiao, J. Y., Leal, A., Noe, M., White, J. R., Arun, A. S., Hruban, C., Annapragada, A. V., Jensen, S. Ø., Ørntoft, M.-B. W. … Velculescu, V. E. (2021). Detection and characterization of lung cancer using cell-free DNA fragmentomes. *Nature Communications*, *12*(1), 1-14.

Moen, R., & Norman, C. (2009, September 17). The history of the PDCA cycle. In *Proceedings of the 7th ANQ Congress*, Tokyo. Retrieved from https://rauterberg.employee.id.tue.nl/lecturenotes/DG000%20DRP-R/references/Moen-Norman-2009.pdf

Mühlfeld, C., Gehr, P., & Rothen-Rutishauser, B. (2008). Translocation and cellular entering mechanisms of nanoparticles in the respiratory tract. *Swiss Medical Weekly*, *138*(27-28), 387-391.

National Dust Disease Taskforce. (2021). *Final Report to Minister for Health and Aged Care*. Australian Government. Retrieved from https://www1.health.gov.au/internet/main/publishing.nsf/Content/562CF83B7AECFC8FCA2584420002B113/$File/NDDT-Final-Report-June-2021.pdf

9News Staff (2020, August 21). Asbestos found on new Sydney ferry vessels. *9News.* Retrieved from https://www.9news.com.au/national/sydney-ferries-asbestos-found-new-boats-made-overseas/fb009706-217d-4bbe-b0fb-93ffe15aa4f7

NOHSC (National Occupational Health and Safety Commission). (1994). *National Model Regulations for the Control of Workplace Hazardous Substances. [NOHSC:1005 (1994)]*. Australian Government. Retrieved from https://webarchive.nla.gov.au/tep/49377

NOHSC (National Occupational Health and Safety Commission). (2005). *Guidance note on the membrane filter method for estimating airborne asbestos fibres [NOHSC: 3003 (2005)]* (2nd ed.). Australian Government. Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1702/guidancenote_membranefiltermethodforestimatingairborneasbestosfibres_2ndedition_nohsc3003-2005_pdf.pdf

NSWDPI (NSW Department of Primary Industries). (2008). *Guideline for the management of diesel engine pollutants in underground environments: MDG 29.* Retrieved from https://www.resourcesregulator.nsw.gov.au/sites/default/files/documents/mdg-29.pdf

NSW Government. (2013). *Work Health and Safety (Mines and Petroleum Sites) Act 2013*. Retrieved from https://legislation.nsw.gov.au/view/html/inforce/current/act-2013-054

NSW Government. (2014). *Work Health and Safety (Mines) Regulation 2014*. Retrieved from https://www.legislation.nsw.gov.au/regulations/2014-799.pdf

NSW Government. (2019). *Workers' Compensation (Dust Diseases) Act 1942*. Retrieved from https://legislation.nsw.gov.au/view/html/inforce/current/act-1942-014#sec.1

NSW Government. (2020). *Work Health and Safety Act 2011*. Retrieved from https://legislation.nsw.gov.au/view/html/inforce/current/act-2011-010#statusinformation

NSW Health. (2021). *Lead exposure in children*. NSW Government. Retrieved from https://www.health.nsw.gov.au/environment/factsheets/Pages/lead-exposure-children.aspx

Oberdörster, G., Oberdörster, E., & Oberdörster, J. (2005). Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. *Environmental Health Perspectives*, *113*(7), 823-839.

O'Donnell, G. E., & Mazereeuw, M. (2020). Biological monitoring of chemical exposure. In S. Reed, D. Pisaniello & G. Benke (Eds), *Principles of occupational health & hygiene: An introduction* (3rd ed., pp. 283-297). Routledge.

Paustenbach, D. J., Cowan, D. M., & Sahmel, J. (2011). The history and biological basis of occupational exposure limits for chemical agents. In V. E. Rose & B. Cohrssen (Eds), *Patty's industrial hygiene* (6th ed., pp. 865-955). John Wiley & Sons.

Queensland Health. (2020). *Notifiable dust lung disease register*. Queensland Government. Retrieved from https://www.health.qld.gov.au/public-health/industry-environment/dust-lung-disease-register

RACP (Royal Australasian College of Physicians). (2020). *Australasian Faculty of Occupational and Environmental Medicine.* Retrieved from https://www.racp.edu.au/about/college-structure/australasian-faculty-of-occupational-and-environmental-medicine

Roberts, A. (2019). What is a micron: A study of particles. *US Home Filter*. Retrieved from https://ushomefilter.com/what-is-a-micron-a-study-of-particles/

SA (Standards Australia). (1997). *AS 4260–1997 High efficiency particulate air (HEPA) filters – classification, construction and performance*.

SA (Standards Australia). (2006). *AS 3853.1–2006 Health and safety in welding and allied processes – sampling of airborne particles and gases in the operator's breathing zone. Part 1: Sampling of airborne particles.*

SA (Standards Australia). (2009a). *AS 3640–2009 Workplace atmospheres – method for sampling and gravimetric determination of inhalable dust*.

SA (Standards Australia). (2009b). *AS 2985–2009 Workplace atmospheres – method for sampling and gravimetric determination of respirable dust*.

SA/SNZ (Standards Australia / Standards New Zealand). (2009). *AS/NZS 1715:2009 Selection, use and maintenance of respiratory protective equipment*.

SA/SNZ (Standards Australia / Standards New Zealand). (2012). *AS/NZS 1716:2012 Respiratory protective devices*.

SA/SNZ (Standards Australia / Standards New Zealand). (2017). *AS/NZS 60335.2.69:2017 Household and similar electrical appliances – safety, part 2.69: Particular requirements for wet and dry vacuum cleaners, including power brush, for commercial use*.

Steer, C., & Langley, C. (2020). The hazardous work environment: The occupational hygiene challenge. In S. Reed, D. Pisaniello & G. Benke (Eds), *Principles of occupational health & hygiene: An introduction* (3rd ed., pp. 1-26). Routledge.

Sung, H., Ferlay, J., Siegel, R. L., Laversanne, M., Soerjomataram, I., Jemal, A., & Bray, F. (2021). Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians*, *71*(3), 209-249.

SWA (Safe Work Australia). (2013). *Guidance on the interpretation of workplace exposure standards for airborne contaminants*. Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1705/guidance-interpretation-workplace-exposure-standards-airborne-contaminants-v2.pdf

SWA (Safe Work Australia). (2018a). *Comparison of workers' compensation arrangements in Australia and New Zealand* (26th ed.). Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1812/comparison-workers-compensation-arrangements-australia-and-new-zealand-2018.pdf

SWA (Safe Work Australia). (2018b). *How to manage work health and safety risks: Code of practice*. Retrieved from https://www.safeworkaustralia.gov.au/doc/model-codes-practice/model-code-practice-how-manage-work-health-and-safety-risks

SWA (Safe Work Australia). (2018c). *WES review 2018. WES methodology: Recommending health-based workplace exposure standards and notations.* Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1806/wes_methodology_recommending_health-based_workplace_exposure_standards_and_notations.pdf

SWA (Safe Work Australia). (2019). *Workplace exposure standards for airborne contaminants*. Retrieved from https://www.safeworkaustralia.gov.au/system/files/documents/1912/workplace-exposure-standards-airborne-contaminants.pdf

SWA (Safe Work Australia). (2020a). *Health monitoring for persons conducting a business or undertaking guide*. Retrieved from https://www.safeworkaustralia.gov.au/doc/health-monitoring-persons-conducting-business-or-undertaking-guide

SWA (Safe Work Australia). (2020b). *Health monitoring: Guide for registered medical practitioners*. Retrieved from https://www.safeworkaustralia.gov.au/resources-and-publications/guidance-materials/health-monitoring-registered-medical-practitioners-guide

SWA (Safe Work Australia). (2020c). *How to safely remove asbestos: Code of practice.* Retrieved from https://www.safeworkaustralia.gov.au/sites/default/files/2020-07/model_code_of_practice_how_to_safely_remove_asbestos.pdf

SWA (Safe Work Australia). (2020d). *Preparation of safety data sheets for hazardous chemicals: Code of practice.* Retrieved from https://www.safeworkaustralia.gov.au/doc/model-codes-practice/model-code-practice-preparation-safety-data-sheets-hazardous-chemicals

SWA (Safe Work Australia). (2021a). *Australian workers' compensation statistics 2019-20*. Retrieved from https://www.safeworkaustralia.gov.au/doc/australian-workers-compensation-statistics-2019-20

SWA (Safe Work Australia). (2021b). *Effective control measures for managing risks in the workplace.* (Infographics – Clean air. Clear lungs.) Retrieved from https://www.safeworkaustralia.gov.au/clearlungs/infographics

SWA (Safe Work Australia). (2021c). *Managing the risks of respirable crystalline silica from engineered stone in the workplace: Code of practice*. Retrieved from https://www.safeworkaustralia.gov.au/doc/model-code-practice-managing-risks-respirable-crystalline-silica-engineered-stone-workplace

SWA (Safe Work Australia). (2021d). *Welding processes: Code of practice*. Retrieved from https://www.safeworkaustralia.gov.au/doc/model-code-practice-welding-processes

SWA (Safe Work Australia). (2022). *Model Work Health and Safety Regulations.* Parliamentary Counsel's Committee. Retrieved from https://www.safeworkaustralia.gov.au/doc/model-whs-regulations

Valentine, R., & Kennedy, J. G. L. (2001). Inhalation toxicology. In A. W. Hayes (Ed.), *Principles and methods of toxicology* (4th ed., pp 1085-1143). Taylor & Francis.

Winder, C. (2004). Occupational respiratory diseases. In C. Winder & N. H. Stacey (Eds), *Occupational toxicology* (pp. 71-114). CRC Press.

WorkSafe Queensland. (2017). *Maintenance, inspection and testing of H-class vacuum cleaners.* Retrieved from https://www.asbestos.qld.gov.au/sites/default/files/asbestos-maintenance-inspection-testing-h-class-vacuum-cleaners.pdf?v=1552446290

Zosky, G. R., Hoy, R. F., Silverstone, E. J., Brims, F. J., Miles, S., Johnson, A. R., Gibson, P. G., & Yates, D. H. (2016). Coal workers' pneumoconiosis: An Australian perspective. *Medical Journal of Australia*, *204*(11), 414-418.

Appendix: Glossary and acronyms

ACGIH	American Conference of Governmental Industrial Hygienists. For additional information: https://www.acgih.org/
AICIS	Australian Industrial Chemicals Introduction Scheme (AICIS replaced NICNAS on 1 July 2020). For additional information: https://www.industrialchemicals.gov.au/
AIOH	The Australian Institute of Occupational Hygienists Inc. https://www.aioh.org.au/
Asbestos	The fibrous form of the mineral silicates belonging to the serpentine and amphibole groups of rock-forming minerals. Regulated forms include: actinolite, amosite, anthophyllite, chrysotile, crocidolite and tremolite asbestos. Common commercial forms used in manufacturing products included chrysotile (white) asbestos, amosite (brown) and crocidolite (blue) asbestos.
Bowtie analysis	An analytical method for identifying and reviewing controls intended to prevent or mitigate a specific unwanted event.
Certified Occupational Hygienist (COH)®	Certified Occupational Hygienist. The highest level of professional occupational hygienist in Australia. Certified occupational hygienists must demonstrate and maintain skills and knowledge via ongoing education and professional practice.
COPD	Chronic obstructive pulmonary disease
COSHH	UK Control of Substances Hazardous to Health Regulations (2002). This regulation specifies requirements for employers to ensure controls are in place to protect worker health.
Critical control	A control that is crucial to preventing the event or mitigating the consequences of the event. The absence or failure of a critical control would significantly increase the risk despite the existence of the other controls. In addition, a control that prevents more than one unwanted event or mitigates more than one consequence is normally classified as critical.
DFF	Dusts, fumes and fibres
Dose	Dose is a function of concentration or amount of a substance and duration of exposure to that substance

Friable	Asbestos-containing material that is in a powder form or that can be crumbled, pulverised or reduced to a powder by hand pressure when dry.
Inhalable	Particles that can enter the human respiratory tract. Inhalable particles are <100 micrometres in size as defined by ISO 7708: Air quality – Particle size fraction definitions (ISO (International Organization for Standardization) 1995).
***In vitro* toxicology**	Application of cell culture techniques in toxicological studies performed in a vitreous media (e.g. glass or plastic) outside the body.
***In vivo* toxicology**	Conventional methods of toxicological assessments based on whole animal studies. A basic assumption of animal studies is that chemicals that cause adverse effects in animals, also cause such effects in humans.
HOC	Hierarchy of Control. A structured system utilised for controlling risks in the workplace.
LEV	Local Exhaust Ventilation
Micrometre	One thousandth of a millimetre, or one millionth of a metre. Other terms include micron or μm.
mppcf	Million particles per cubic foot.
MMVF	Man-Made Vitreous Fibre (formerly called synthetic mineral fibres, or SMF).
Mucociliary clearance	Blanket escalator system for removing inhaled particles from the airways.
Nanomaterials	Nanomaterials (NMs) are defined as objects that have at least one dimension in the size range 1-100 nanometres (or 1×10^{-9} metres). Depending on their geometric characteristics many are designed for a specific purpose or function and can take the form of balls, tubes, plates, and many other geometric shapes.
Nanoparticles	Nano-objects or nanomaterials are primary particles with at least one dimension at the nanoscale level (1-100 nm) including nanoparticles, nanofibers and nanoplates. Nanomaterials can be classified in two major categories including unintentionally produced ultrafine particles such as those contained within diesel exhaust, and intentionally manufactured nanoparticles such as titanium dioxide. Engineered nanomaterials are made from different materials such as carbon (e.g. carbon

	nanotubes), metals (e.g. nanosilver), and metal oxides (e.g. zinc oxide). Nanomaterial structures are more likely to be toxic than the same materials in bulk samples. Nanoparticles can be inhaled deeply into the lungs due to their very small size. Regarding their large surface area, they can be more biologically active and available to undergo reactions within human cells.
NATA	National Association of Testing Authorities, Australia. NATA provides accreditation services for facilities seeking to undertake measurement and inspection services against national and international standards. For more information go to https://nata.com.au/.
NOA	Naturally occurring asbestos. This form of asbestos is found naturally in the environment and can impact workplaces such as mining, agriculture, and infrastructure construction.
Non-friable	Asbestos-containing material that is not friable, including materials where the fibres are bound in a permanent matrix, e.g. asbestos cement, vinyl asbestos tiles and electrical backing boards.
Occupational Hygienist	A specialist OHS practitioner skilled in recognising, evaluating and controlling workplace hazards. Occupational hygienists use science to assess hazards and risks to improve work conditions and protect worker health.
OEL	Occupational Exposure Limit
OHS	Occupational Health and Safety
Particle	Minute piece of matter with defined physical boundaries. Particulates (i.e. very small pieces of solid matter) can be generated by many processes and rendered airborne.
PPE	Personal Protective Equipment
Productive cough	A persistent cough that produces mucus
Pulmonary macrophages	A type of phagocytic cells found in the alveoli of the lungs that protect the body by engulfing/ ingesting harmful inhaled particles, bacteria, and dead or dying cells.
RCS	Respirable crystalline silica
Respirable	Particles that can enter the human respiratory tract and be deposited in the lower lungs. Respirable particles are generally <10 micrometres in size as defined by ISO 7708: Air quality –

	Particle size fraction definitions (ISO (International Organization for Standardization) 1995).
Respirable fibre	Fibres which have the aerodynamic characteristics to be inhaled and penetrate to the lower lung tissue. They are defined by the following geometric criteria: Greater than 5 micrometres in length, and Less than 3 micrometres wide, with an Aspect ratio of greater than 3:1
Silica	Silicon dioxide (SiO_2) which can be present in 2 forms, crystalline and amorphous. The crystalline form includes ɑ-quartz, cristobalite and tridymite; amorphous forms include diatomaceous earth and silica fume. The crystalline form is more toxic, and is often referred to as crystalline silica, or silica. The most common form of crystalline silica encountered in the workplace is ɑ-quartz (or quartz).
SEG	Similar exposure group. A group of workers who have the same risks of exposure to hazards in a workplace.
Smoke	Result of incomplete combustion from thermal processes. The composition of smoke is complex due to variable mixtures of chemicals present and it can comprise of particles, gas and vapour elements. The particles within smoke are <1 micrometre in size. Examples include cigarette smoke and bush fire emissions.
WES	Workplace Exposure Standard. For additional information on the exposure standards, refer www.safework.gov.au