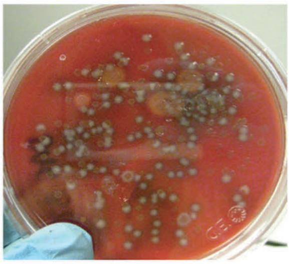

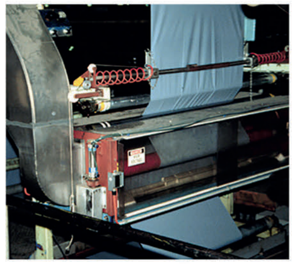





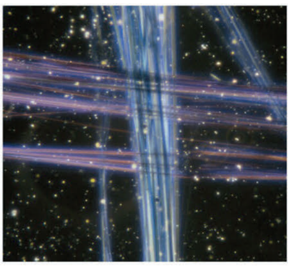

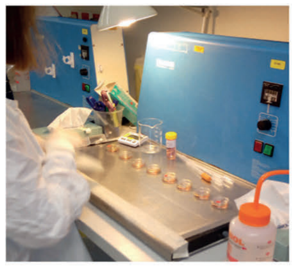


Edited by
SUE REED,
DINO PISANIELLO
AND **GEZA BENKE**

Third edition

PRINCIPLES OF
OCCUPATIONAL HEALTH & HYGIENE

AN INTRODUCTION

Principles of
Occupational Health & Hygiene

Principles of **Occupational Health & Hygiene**

An introduction

3rd edition

Edited by Sue Reed, Dino Pisaniello & Geza Benke

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Contents

Foreword

The Australian Institute of Occupational Hygienists (AIOH) defines occupational hygiene as the art and science of occupational disease prevention. More specifically, occupational hygiene addresses the anticipation, recognition, evaluation, communication and control of environmental hazards in, or arising from, the workplace, which can result in injury, illness, impairment, or affect the well-being of workers and members of the community.

The importance of occupational hygiene has been increasingly recognised over the past three centuries. In 1775, surgeon Percival Pott noted an increased incidence of scrotal cancer in English chimney sweeps, documenting the first causal association between workplace exposure to hazards and the subsequent development of disease. Since this time, we have continued to see clusters of occupational diseases associated with particular industries and hazards, including the prevalence of asbestos-related lung diseases in the mid-late 20th century and the recent recognition of accelerated silicosis in manufactured stone workers in 2018.

Over this time, constantly changing technology has created constantly changing workplaces and hazards, highlighting the need to apply the fundamental principles of occupational hygiene to facilitate the anticipation, recognition, evaluation and control of new and emerging hazards.

To promote these principles, the first edition of *Principles of Occupational Health and Hygiene: An Introduction* was published in 2007. This book was based on the 1992 book *Occupational Health and Hygiene Guidebook for the WHSO (Workplace Health and Safety Officer)* written by Dr David Grantham, who generously ceded the rights and royalties for this book to AIOH in 2002.

The new book was aimed at a wide audience of health and safety professionals, and included emerging issues and topics that had become important since the original 1992 book was published. Many respected authors, all AIOH members, freely contributed their time to review the text and deliver updated chapters on their areas of expertise.

In 2013, a second edition of the *Principles of Occupational Health and Hygiene: An Introduction* was published. By this time the book had been adopted as a valued reference source by many occupational health and hygiene professionals and as a standard textbook by a growing number of educational institutions.

Building on this work, most of the second edition's authors have again donated their time to review and update their chapter of expertise to produce the current third edition. *Principles of Occupational Health and Hygiene: An Introduction* remains an ideal resource for students of occupational health and safety, and a professional reference for occupational hygienists, occupational health and safety professionals and anyone working in an occupational health and safety role.

The increased use of this book as a textbook and reference source will promote the application of the principles of occupational hygiene to ensure focus is maintained on prevention of occupational diseases in Australia and overseas.

Dr Julia Norris
AIOH President, 2019

Preface

The ambitious project by the AIOH to revise and expand David Grantham's *Occupational Health and Hygiene Guidebook for the WHSO* began in 2003 under the guidance of Dr Cherilyn Tillman. The result, published in 2007, was the 1st edition of this book, and covered a broad range of topics, which have continued to grow in importance. The 2nd edition was published in 2013, and in 2017, the AIOH initiated work on this 3rd edition.

The editors and the Council of the AIOH thank all the authors and reviewers for their professionalism and attention to detail and for their generous collaboration with us during the project. All of the 30 authors of this 3rd edition are members of the AIOH who have written chapters in their own time, without payment or favour, to support the AIOH in its role of furthering the practice and recognition of occupational hygiene in the Australasian region, and in support of the Australian Work Health and Safety Strategy 2012–2022.

We would like to thank Dr David Grantham for his interest, encouragement and assistance in updating and expanding his original material. In addition, we would like to thank the Council of the AIOH for inviting us to serve as editors of the 3rd edition. It was an honour to be entrusted with delivery of this important publication.

Where appropriate, the book emphasises issues as seen in Australian workplaces such as the coverage of thermal stress, focusing on heat rather than cold. The book refers to Australian legislation where it is appropriate but in the main legislation is not covered in depth due to differences between states. Australian standards are also only referred to where appropriate and in some areas, such as indoor air quality, international standards are discussed. Occupational exposure limits are referred to as OEL standards, and not WES, due to the broad readership of the book, and similarly OHS or H&S is used in preference to WHS.

Finally, we would like to thank our families for their patience, understanding and support during this project, which consumed far more of our lives and free time than we had envisaged.

Associate Professor Sue Reed, Professor Dino Pisaniello and Dr Geza Benke
Perth, 2019

Acknowledgements

The AIOH editorial committee gratefully acknowledges the pioneering work of Dr David Grantham, on which this book was originally based.

We also gratefully acknowledge the invaluable efforts of Dr Cherilyn Tillman, editor of the 1st edition, along with authors who decided not to be involved in the later editions but have allowed their work to be used. The relevant authors are: Dr Ian Grayson (concept of the exposure standard), Dr Steven Brown (indoor air quality), Dr Georgia Sinclair (ionising radiation), Dr Denise Elson (biological hazards).

In addition we would like to acknowledge authors from the 2nd edition who are not part of the 3rd edition, who are: Dr David Grantham AM (Chapter 1: The hazardous work environment: the occupational hygiene challenge; Chapter 3: The concept of the exposure limit strategies for workplace health hazards; and Chapter 4: Control of workplace health hazards), Dr John Edwards (Chapter 2: Occupational health, basic toxicology and epidemiology; and Chapter 10: Biological monitoring of chemical exposure), Geoff Pickford (Chapter 7: Aerosols), Dr Brian Davies AM (Chapter 7: Aerosols), Gary Rhyder (Chapter 8: Metals in the workplace), Noel Tresider AM (Chapter 9: Gases and vapours), Kate Leahy (Chapter 9: Gases and vapours), Michelle Wakelam (Chapter 13: Radiation—ionising and non-ionising), Sarah Thornton (Chapter 16: Biological hazards), Dr Howard Morris (Chapter 17: Emerging and evolving issues) and Dr Bob Rajan OBE (Chapter 17: Emerging and evolving issues).

The editorial committee would also like to thank the many people who have supported this edition by providing images; they are acknowledged individually throughout the text. Images without source citation have been provided by the chapter author/s.

The AIOH is also grateful to the AIOH members who volunteered to peer-review chapters of the book, namely Dr Barry Chesson and Dr Geza Benke (Chapter 1), A. Prof. Susanne Tepe (Chapter 2), Prof. Jacques Oosthuizen (Chapter 3), Kerrie Burton (Chapter 4), Stephen Turner (Chapter 5), Jane Whitelaw (Chapter 6), Prof. Brian Davies (Chapter 7), Gary Rhyder (Chapter 8), Prof. Sue Reed (Chapter 9), Sally North (Chapter 10), Mitchell Thompson (Chapter 11), Dr Kelly Johnstone (Chapter 12), Russell Brown (Chapter 13), Dr Vinod Gopaldasani (Chapter 14), Adelle Liebenberg (Chapter 15) and David Hughes (Chapter 16).

Finally, the editors thank the AIOH council for supporting the project and the AIOH staff for administrative support.

Author biographies

Linda Apthorpe FAIOH COH

Linda Apthorpe has a master's degree in occupational hygiene practice. She has been working in occupational hygiene since 1994, and currently lectures in occupational hygiene at University of Wollongong. She provides consultancy and laboratory services to a wide variety of workplaces, and facilitates training for occupational hygiene students and worker groups. With her analytical background in asbestos, dust and quartz, Linda contributes volunteer technical assistance to the AIOH, National Association of Testing Authorities (NATA) and Proficiency Testing Australia. She has also authored or co-authored various papers in the occupational hygiene field.

Geza Benke FAIOH COH

Geza Benke has a BSc (Physics), MAppSc (Environmental Engineering) and PhD (Epidemiology). He worked with the Victorian Environment Protection Authority for five years before joining the Victorian state government's Occupational Hygiene branch in 1985. His work in occupational hygiene mainly involved noise assessment and control, radiation safety and asbestos work. Since 1994 Geza has undertaken research in a range of occupational and environmental epidemiology studies. He is currently Senior Research Fellow with the Centre for Occupational and Environmental Health, Department of Epidemiology and Preventive Medicine, Monash University.

Jodie Britton MAIOH COH

Jodie Britton has an MSc Occupational Hygiene Practice and a Graduate Diploma in Occupational Health and Safety. She is a Full Member of the AIOH and is also a member of the American Conference of Governmental Industrial Hygienists (ACGIH). Her background in heavy industry spans 29 years and includes 26 years in the Aluminium Smelting Industry. She has extensive practical experience within this field which complements her role as a Specialist Occupational Hygienist for Rio Tinto at the Boyne Island Aluminium Smelter. Her areas of interest include the thermal work environment and coal tar pitch volatiles (CTPV).

David Bromwich FAIOH (Retired)

David Bromwich has an honours degree in physics, master's degrees in both medical physics and occupational hygiene and a research PhD in occupational hygiene. He is a Fellow of the Australian Institute of Occupational Hygienists. He was an academic at

Griffith University for 20 years in the School of Environmental Engineering and is now an adjunct Associate Professor in the School of Medicine, but is largely retired. His interest in industrial ventilation started as a mines inspector in the Northern Territory and continued with his Occupational Hygiene Master's thesis in London and his teaching where he developed an large industrial ventilation laboratory. His research interests were chemical protective clothing, industrial ventilation and exposure visualisation.

Ron Capil FAIOH COH

Ron Capil has a background in Chemistry and a Graduate Diploma in Occupational Hygiene. He has over 45 years' experience including a decade in environmental monitoring and the remainder in occupational hygiene. His occupational hygiene work has involved workplace environment assessments in aluminium smelters and alumina refineries with a major focus on asbestos removal and management. He also provided strategic guidance as principal adviser health and hygiene to a leading Australasian aluminium industry. He is currently providing occupational hygiene consulting services to the aluminium industry.

Kate Cole MAIOH COH

Kate Cole has a BSc (Biotechnology) and master's degrees in engineering and occupational hygiene. A passionate advocate for preserving the health of those who service the construction industry, her key areas of interest are complex work environments including the remediation of contaminated land and tunnel construction. She is a Winston Churchill Fellow where she investigated world's best practice to prevent illness and disease in tunnel construction workers and was named as one of the Top 100 Women of Influence by the *Australian Financial Review* for her work in proactively addressing the issue of silica dust exposure in the construction industry. She is currently the Manager of Occupational Health and Hygiene with Ventia.

Martyn Cross MAIOH

Martyn began his career as a toxicologist working in the UK chemical industry. He has an honours degree in Toxicology, a Master's of Public Health and a PhD. Martyn has considerable experience in Occupational Hygiene, as Occupational Hygienist for WorkSafe WA, the WA Department of Health, and Principal Occupational Hygienist for Minara Resources. Martyn has 35+ years as a safety professional and occupational hygienist in a variety of industries. He is currently Senior Lecturer and Principal Supervisor, supervising Masters' and PhD students at Edith Cowan University.

Maggie Davidson MAIOH

Dr Maggie Davidson MAIOH is a lecturer and researcher in the fields of occupational hygiene and environmental health based at Western Sydney University and an Adjunct Researcher with Edith Cowan University. Maggie has been undertaking research in the field of biological hazards and bioareosols for fifteen years, completing her post doctoral research on respiratory hazards associated with working in Colorado dairies at the NIOSH High Plains Intermountain Centre for Health and Safety, and PhD on the impact of smoking bans on indoor and outdoor air quality in NSW licensed clubs at UWS. Current research projects include promoting health and safety in the emergent Australian medicinal cannabis and industrial hemp industries, worker exposure to solvents and repairable crystalline silica in the manufacture of artificial stone products, and a citizen science project investigating ambient air quality in the Blue Mountains, NSW.

Ross Di Corleto FAIOH COH

Ross Di Corleto has a BSc in applied chemistry, a graduate diploma in occupational hygiene, a master's degree by research thesis in heat stress and a PhD in occupational health in the area of polycyclic aromatic hydrocarbon exposure. He has worked for over 40 years in the areas of power generation, minerals, mining, refining and smelting. This involvement has been predominantly across the chemical, health, safety and environment fields, with occupational hygiene the main emphasis. The thermal environment and its impact on the industrial employee has been a key area of Ross's interest and involvement. He is currently the Principal Consultant at Monitor Consulting Services.

Ian Firth FAIOH COH

Ian Firth has a BSc (Hons) in zoology and MSc in applied biology (toxicology). He has over 38 years' work experience, including a decade in environmental sciences and the rest in occupational hygiene. His environmental work has principally involved research on freshwater animal toxicology, environmental management and acid rock drainage management. His occupational hygiene work has involved workplace environment assessment in hard rock mining settings and in smelting in the zinc/lead and aluminium industries, and he has provided tactical and strategic advice on health management as the corporate principal adviser of a leading international resources company. He is currently a consultant providing occupational hygiene services to a variety of clients.

Garry Gately FAIOH (Retired)

Garry Gately has a Diploma of Applied Chemistry and a Master of Chemistry specialising in analytical chemistry and held a CIH. He had over 35 years of industrial experience, of which more than 30 years was in occupational health and safety. Garry was the Corporate Hygienist and Corporate Lead SH&E Auditor for Orica (formerly ICI Australia and ICI plc) and he had extensive experience in many technologies and industrial sectors.

Robert Golec FAIOH COH

Robert Golec holds a Bachelor's degree in Applied Chemistry, a Graduate Diploma in Analytical Chemistry and a Master of Applied Science in Applied Toxicology. He has been a member of the AIOH since 1985 and is a certified occupational hygienist and Fellow of the Institute. Robert has over 36 years' experience in occupational hygiene, initially with the state government and then in a consulting capacity as Principal Occupational Hygienist with AMCOSH Pty Ltd. He is a long-standing member of the AIOH Exposure Standards Committee, a member of Standards Australia Committee CH/31 Methods for Examination of Workplace Atmospheres and a member of the National Association of Testing Authorities' (NATA) Life Sciences Accreditation Advisory Committee and an Occupational Hygiene Technical Adviser to NATA as well as a Technical Assessor for Occupational Hygiene monitoring and analysis.

Terry Gorman FAIOH COH

Terry Gorman has a Master's degree in Safety Science, is a certified occupational hygienist and has been involved in workplace safety and hygiene for over 30 years. He worked in production, safety and hygiene at the Lucas Heights reactor site for 20 years before joining 3M Australia in 1999. He is a member of the Australian/New Zealand Standards Committee responsible for respiratory protection (AS/NZS 1715 and 1716) as well as the Eye/Face Protection Standards Committee (AS/NZS 1337 and 1338). He currently represents Standards Australia on the International Standards Organisation (ISO) Committee TC94/SC15, a team of international representatives creating a set of global respiratory standards.

Beno Groothoff FAIOH COH

Beno has a background in mechanical engineering, a post graduate in occupational health and safety and a Master's in health sciences, majoring in occupational health and safety. He has been working in the fields of environmental pollution control, occupational hygiene and health and safety since 1970. In Queensland he has worked in private practice and government positions in both environmental protection and work health and safety. His occupational hygiene work has involved workplace environment audits and assessment (chemical, dust, noise, acoustic shock, human vibration, radiation, heat stress, accident investigation, etc.) in a large variety of industries in both the Netherlands and Queensland. In 2015 he was the course coordinator at QUT's Occupational Hygiene and Toxicology course, updating and presenting lectures to post graduate and master's students. He is a member of the AV10 Committee of Standards Australia on occupational noise and vibration. Beno's company, Environmental Directions Pty Ltd, provides training and occupational hygiene services to a variety of clients in industry, mining, universities and government agencies.

Jennifer Hines MAIOH COH

Jennifer Hines has a BSc with Honours, a Graduate Diploma and a Master's in Occupational Hygiene, and is currently a doctoral candidate researching emissions-based maintenance of diesel engines and its benefits to the workplace. Jennifer has worked extensively in heavy industry including alumina refining, copper refining and smelting, and underground coal mining. She is the director of EHS Solutions and is passionate about teaching and encouraging others into the world of occupational hygiene. Jennifer facilitates the Australian Department of Defence Monitoring of Occupational Hygiene Course. She is a lecturer at the University of Wollongong and has served on several AIOH committees.

Martin Jennings FAIOH COH

Martin Jennings is an occupational hygienist with nearly 40 years' experience in government and in the nuclear, defence and chemical industries. His qualifications include a BSc from Surrey University, a Master of Science (MSc) in Occupational Hygiene from the London School of Hygiene and Tropical Medicine and a further Master's degree in Administration from Griffith University. He is a CIH in the United States. He is a past president of the Australian Institute of Occupational Hygienists.

Ryan Kift

Ryan Kift has a PhD in Occupational Hygiene and undergraduate degrees in Environmental Health and Occupational Health and Environment. Ryan has over 15 years of occupational hygiene and safety experience in local government, academic and industrial settings. He has been involved in occupational hygiene management on large construction projects, and worked in the oil and gas and metals industries. He is currently a senior lecture at CQ University, Australia and a Senior Consultant for GCG Health, Safety, Hygiene. Ryan has published over 50 scientific papers in the areas of biological and dust monitoring, cognitive ergonomics and safety management.

Caroline Langley FAIOH COH

Caroline Langley has a BSc, a GDip (Occup Hygiene), an MSafetySc and was a Certified Occupational Hygienist until her recent retirement. She has over 30 years of professional experience in health, safety and occupational/environmental hygiene. She held corporate OHSE positions in research organisations, developing specialist expertise in laboratory safety, before moving to the consulting sector as a director. As a consultant Caroline focused on enhancing worker health, leading a team providing a full suite of professional occupational hygiene consulting and analytical services to clients in the mining, manufacturing, food processing, aquaculture, construction, utilities, shipping, health, government and education sectors. She also continued to provide professional advice on laboratory design as well as safety in research, teaching and production laboratories. Caroline is a past president of the Australian Institute of Occupational Hygienists (AIOH) and is a member of the AIOH Foundation Board.

So Young Lee

So Young Lee has Bachelor of Business Accounting, associate degree of Optometry and Master of Public Health (Environmental Health) in South Korea. She has over 10 years' optometry, optical companies and epidemiological research experience in South Korea and is now doing a PhD in Public Health (Adelaide Exposure Science and Health) in the University of Adelaide. Her current research is about the photochemical damage from blue light exposure in the workplace and she is also interested in the health effects of workers from exposure to intense light sources.

Elaine Lindars MAIOH COH

Elaine Lindars has a PhD in geochemistry, a post graduate in industrial hygiene and an honours degree in environmental chemistry. She is a Certified Occupational Hygienist, a Chartered Professional Member of the Safety Institute of Australia, a Chartered Chemist with the Royal Australian Chemical Institute and an adjunct lecturer with Edith Cowan University. Elaine has worked with the AIOH for over ten years and is the first president of Workplace Health Without Borders (Australia). Elaine has 30 years' 'experience in occupational, environmental and analytical chemistry, with 20 scientific papers/conference publications, and is now an owner of the OHMS Hygiene, OHMS Environment and OHMS Training consultancies.

Martin Mazereeuw

Dr Martin Mazereeuw gained his PhD in analytical chemistry at the Leiden Academic Centre for Drug Research at Leiden University in The Netherlands and has since worked in several analytical and managerial roles within biotechnology, research support and large industry. He has been a GLP study director for food safety studies and implemented the first NATA accredited ISO17025 system for research within NSW. Martin joined TestSafe Australia in 2012 as the manager of the Chemical Analysis Branch of TestSafe Australia, which is part of SafeWork NSW.

Greg O'Donnell MAIOH (Retired)

Greg O'Donnell has a PhD in chemistry and an undergraduate degree in Applied Science majoring in chemistry and is a Chartered Chemist with the Royal Australian Chemical Institute. He has been working in occupational exposure chemical analysis for over 27 years with SafeWork NSW. He has been a member of the SafeWork NSW Biological Occupational Exposure Limit (BOEL) committee for 23 years and is the current chairman. Greg is also the chairman of the Standards Australia Committee CH-31 Methods for Examination of Workplace Atmospheres. He is a member of the AIOH Exposure Standards Committee and was a member of the Safe Work Australia's Health Monitoring Review Expert Working Group. He has published 14 scientific papers and over 35 conference presentations in the field of occupational health and hygiene, with particular interest in biological monitoring. He is an honorary associate of Macquarie University.

Dino Pisaniello FAIOH COH

Dino Pisaniello has a PhD in chemistry and a Master's degree in Public Health. He is a Fellow of the Safety Institute of Australia and the Royal Australian Chemical Institute. Dino has served as president of AIOH, chairman of the Congress of Occupational Safety and Health Association Presidents (2001–5) and Australian Secretary for the International Commission on Occupational Health. He is currently Professor in Occupational and Environmental Hygiene in the School of Public Health at the University of Adelaide. Dino has published over 250 scientific papers and technical reports. His research interests include chemical exposure assessment and control, intervention research, occupational and environmental epidemiology, work and vision, heat and work injury and health and safety education.

Wayne Powys FAIOH COH

Wayne Powys completed the Graduate Examination of the Royal Society of Chemistry (UK) and is a Member of the Royal Australian Chemical Institute and a Chartered Chemist. He spent the first part of his career working in the field of analytical chemistry, principally in the water sector in the UK and later the oil and gas sector in Western Australia. After obtaining a Graduate Diploma of Occupational Hygiene, he moved into the discipline and worked for well over twenty years in the oil and gas sector in Western Australia, during which time he completed an MSc degree in Occupational Hygiene.

Sue Reed FAIOH COH

Sue Reed has a Bachelor of Science, a Master of Engineering Science, a Master of Science and a PhD in Occupational Hygiene. She is a CIH in the United States. Sue has over 40 years of occupational hygiene experience in government and defence, and as an academic. She is currently an associate professor at Edith Cowan University, Perth, and director of a small occupational hygiene consultancy. Sue has published over 50 scientific papers and technical reports on subjects including chemical exposure assessment and control, noise, indoor air quality and OHS education, specifically in relation to occupational hygiene. She is a past president of the Australian Institute of Occupational Hygienists.

Roy Schmid MAIOH COH

Roy Schmid has a Bachelor of Science and honours degree in chemistry and a Graduate Diploma of Occupational Hygiene, and is a CIH in the United States. He has over 25 years' experience in occupational health and safety within the tertiary education and research sector as the hygienist and WHS manager for the Australian National University and currently with the Department of Defence. He has an extensive knowledge of conventional and novel workplace hazards.

Michael Shepherd FAIOH COH

Michael Shepherd has a Bachelor of Science in Chemistry and a Graduate Diploma in Occupational Health and Safety, is a Chartered Chemist, a Certified Occupational Hygienist and Fellow of the Australian Institute of Occupational Hygienists. Michael has over twenty-five years' experience in multidisciplinary occupational health and safety assessments and advises government on health and safety policy and legislation. Michael's specialties are recognition, evaluation and control of workplace hazards. His main expertise includes water quality, indoor air quality, asbestos, dust, mould and hazardous chemicals. He is currently the Principal Occupational Hygienist for COHLABS Pty Ltd.

Charles Steer FAIOH COH

Charles Steer has a BAppSc (Applied Chemistry), a GDip (Environmental Studies) and completed the 13-week University of Sydney post-graduate course in occupational hygiene. He has had extensive experience in health, safety, occupational hygiene, environment, risk management and chemical technology, holding senior corporate positions in these areas in the electricity industry in South Australia until mid-2000. He has run his own consultancy since that time, mainly focused on developing sustainable occupational health and hygiene management frameworks, occupational hygiene consulting and mentoring as well as exposure assessment and hands on monitoring. He is a past president of the Australian Institute of Occupational Hygienists and is currently Chair of the AIOH Foundation.

Aleks Todorovic MAIOH

Aleks Todorovic has a Master of Science (Occupational Hygiene Practice). He has over 23 years' experience in the industry as a supplier of occupational hygiene monitoring and detection equipment, and for the last 17 years has owned and managed Active Environmental Solutions (AES). Throughout this period he has been involved in the development and testing of many new types of monitoring instrumentation, focusing mainly on chemicals in the petrochemical, defence and emergency services industries. He has also been a guest lecturer and presenter at various tertiary institutions and associations. His current direction is in the advancement of connected real-time wireless detection and monitoring solutions in the occupational hygiene and safety industries, with an emphasis on total worker exposure from simultaneous multiple stressors.

Jane Whitelaw FAIOH COH

Jane Whitelaw has a Master of Applied Science (Environmental Health) and a Post Graduate Diploma in OHS and is a Certified Occupational Hygienist, Certified Industrial Hygienist and Fellow of AIOH. She had over 25 years' experience in heavy manufacturing industries before moving into teaching and research at the University of Wollongong; where she is co-ordinator of the Occupational Hygiene program. She is a member of the AIOH Professional Development and Education committee and the AIOH representative on the AOHSEAB (Australian Occupational Health and Safety Accreditation Board). Jane's research interests are in protecting worker health from chemical and physical hazards, and her major grants and research have been in evaluating the efficacy of protective equipment. She has also authored numerous papers in the occupational hygiene field.

Abbreviations and definitions

A	ampere
A/m	ampere per metre
ABC	Australian Building Code
ABCB	Australian Building Codes Board
AC	asbestos cement
ACGIH®	American Conference of Governmental Industrial Hygienists
ACIF	Australian Construction Industry Forum
ACM	asbestos-containing materials
ACPSEM	Australasian College of Physical Scientists and Engineers in Medicine
ADI	acceptable daily intake
AFOM	Australasian Faculty of Occupational Medicine
AIHA	American Industrial Hygiene Association
AIOH	Australian Institute of Occupational Hygienists
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
ALI	annual limit of intake
ANSTO	Australian Nuclear Science and Technology Organisation
APVMA	Australian Pesticides and Veterinary Medicines Authority
ARPANSA	Australasian Radiation Protection and Nuclear Safety Agency
ARPS	Australian Radiation Protection Society
AS	Standards Australia
AS/NZS	Australian/New Zealand Standard
ASCC	Australian Safety and Compensation Council (now Safe Work Australia)
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ASTM	American Society for Testing and Materials
B	magnetic flux density
BCIRA	British Cast Iron Research Association
BEI®	biological exposure index
BET	basic effective temperature
BMI	body mass index

BMRC	British Medical Research Council
BOHS	British Occupational Hygiene Society
Bq	becquerel
BSE	bovine spongiform encephalopathy
°C	degrees Celsius
C/kg	coulomb per kilogram
CCA	copper-chrome-arsenic
CCT	correlated colour temperature
cd	candela
CDC	Centers for Disease Control
CEC	Commission of European Communities
CFC	chlorofluorocarbons
CFU	colony-forming units
Ci	Curie
CJD	Creutzfeldt-Jakob disease
cm	centimetre
CNF	carbon nanofibre
CNT	carbon nanotubes
COH	Certified Occupational Hygienist (COH)® status is recognition of a professionally competent, independent and ethical practitioner and an industry leader in occupational hygiene
CoP	Code of Practice
COPD	chronic obstructive pulmonary disease
COSHH	control of substances hazardous to health
CPC	chemical protective clothing
CRI	colour rendering index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTPV	coal tar pitch volatiles
CWP	coal workers' pneumoconiosis
D	absorbed dose
d-ALA	*d*-aminolaevulinic acid
dB	decibel
dB(A)	decibel measured on the A-weighting scale
dB(C)	decibel measured on the C-weighting scale
DC	direct current
DFG	Deutsche Forschungsgemeinschaft
DNA	deoxyribonucleic acid
DND	daily noise dose
DNELS	derived no-effect levels
DP	diesel particulate
DPM	diesel particulate matter
E	illuminance (Chapter 15)
E	effective dose (Section 13.2.9.3)

E	electric field strength (Section 13.3.6.3)
$E_{A,T}$	A-weighted noise exposure
EAD	equivalent aerodynamic diameter
EAV	daily exposure action
EC	elemental carbon
EC	European Commission
ED_{50}	dose causing 50 per cent of maximal effect
EDTA	ethylenediaminetetraacetic acid
E_{eff}	effective irradiance
ELF	extremely low frequency
ELV	daily exposure limit (vibration)
EM	electromagnetic
EMB	eosin methylene blue
ES	exposure standard
ETS	environmental tobacco smoke
ETSI	European Telecommunications Standards Institute
eV	electron-volt
f	frequency
FCA	flux-cored arc
FTIR	Fourier transform infrared spectrometry
g	gram
G	Gauss; 10,000G = 1 T (Chapter 13.3.5.2)
GHS	Global Harmonized System
GHz	gigahertz
GM	Geiger-Müller
GM	geometric mean
GMO	genetically manipulated organisms
GSD	geometric standard deviation
Gy	gray
H	magnetic field strength
H&S	health and safety
HAVS	hand-arm vibration syndrome
HAZOP	hazard and operability study
HDM	house dust mite
HEPA	high-efficiency particulate air filter
HID	high-intensity discharge
HIV	human immunodeficiency virus
HML	high, medium-low
HP	hypersensitivity pneumonitis
HPD	hearing protective device
HPE	hearing protective equipment
HSE	Health and Safety Executive (United Kingdom)
H_T	equivalent dose

HTL	hygienic threshold limits
HVAC	heating, ventilation and air-conditioning
Hz	hertz
I	current
IAEA	International Atomic Energy Agency
IAQ	indoor air quality
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICP	inductively coupled argon plasma
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
IEQ	Indoor Environment Quality
IH	industrial hygiene
IHSTAT	Industrial Hygiene Statistical Package
ILO	International Labor Office
in vitro	in an artificial environment outside the living organism
in vivo	within a living organism
IOHA	International Occupational Hygiene Association
IOM	Institute of Occupational Medicine
ipRGC	intrinsically photosensitive retinal ganglion cells
IR	infrared
IR-A	wavelengths 780 to 1400 nm and frequencies around 10^{14} Hz
IR-B	wavelengths 1400 to 3000 nm and frequencies around 10^{14} Hz
IR-C	wavelengths 3000 nm to 1 mm and frequencies around 10^{11}–10^{14} Hz
IREQ	required clothing index
ISO	International Organization for Standardization
IVC	individually ventilated cage
J	joule
K	kelvin
kg	kilogram
kHz	kilohertz
km	kilometre
kPa	kilopascals
L	litre
L	luminance (Chapter 15)
L/min	litres per minute
LAA	laboratory animal allergy
$L_{Aeq,x}$	sound pressure level, A-weighted, over time period 'x'
LCD	liquid crystal display
LCL	lower confidence limit
$L_{c,\ peak}$	sound pressure level, C-weighted, peak
LC_{50}	lethal concentration for 50 per cent of specific population
LD_{50}	lethal dose for 50 per cent of specific population

LED	light-emitting diode
Leq	equivalent sound pressure level
LEV	local exhaust ventilation
LLS	laser light-scattering
lm	lumen
LOAEL	lowest observed adverse effect levels
low-E	low emissivity
LPG	liquid petroleum gas
lx	lux
m	metre
m/s	metres per second
m/s^2	metres per second squared
m^2	square metres
MA	mandelic acid
MCS	multiple chemical sensitivity
MDHS	methods for the determination of hazardous substances
MDI	methylene bisphenyl isocyanate
MEA	malt extract agar
MEC	minimum emission concentration
MEPS	minimum energy performance standards
mg/kg	milligrams per kilogram
mg/m^3	milligrams per cubic metre
mGy	milligray
MHz	megahertz
ml	millilitre (10^{-3} litre)
MMA	manual metal arc
MMI	mucous membrane irritation
MMT	methylcyclopentadienyl manganese tricarbonyl
MPP	mucus-penetrating particles
MOCA	a curing agent (4,4′-methylenebis(2-chloroaniline))
$ms^{-1.75}$	metres per second to the power of 1.75
MSDS	material safety data sheet (now called SDS—safety data sheet)
mSv	millisievert
mT	Millitesla
MVOC	microbial volatile organic compounds
MVUE	estimate of the arithmetic mean (Est. AM)
mW	milliwatt
NAL	National Acoustics Laboratories
nanoparticle	particle in size range of 0 to 100 nm
NATA	National Association of Testing Authorities
NEPM	National Environment Protection Measures
nGy	nanogray
NHMRC	National Health and Medical Research Council

NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIHL	noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre (10^{-9} metre)
NOA	naturally occurring asbestos
NOAEL	no observed adverse effect levels
NOHSC	National Occupational Health and Safety Commission
NORA	National Occupational Research Agenda
NORM	naturally occurring radioactive material
NRR	American system of determining the expected sound attenuation of a hearing protector
NVvA	Nederlandse Vereniging voor Arbeidshygiëne
OARS	Occupational Alliance for Risk Science
OCSEH	Office of Chemical Safety and Environmental Health
ODTS	organic toxic dust syndrome
OECD	Organisation for Economic Co-operation and Development
OEL	occupational exposure limits
OGTR	Office of the Gene Technology Regulator
OHS	occupational health and safety
OP	organophosphates
OSHA	Occupational Safety and Health Administration
p	pressure
P_0	reference sound pressure
Pa	pascal
PAH	polycyclic aromatic hydrocarbon
PAPR	powered air-purifying respirator
PC	physical containment
PCBU	person in control of a business or undertaking
PGA	phenylglyoxylic acid
PHS	predicted heat strain
PLM	polarised light microscope
$PM_{2.5}$	particulate mass with a median aerodynamic equivalent diameter cut-point of 2.5 μm
PM_{10}	particulate mass with a median aerodynamic equivalent diameter cut-point of 10 μm
PMF	progressive massive fibrosis
PPE	personal protective equipment
ppm	parts per million
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride
QAP	quarantine-approved premises
R	roentgen

RCS	Reuter Centrifugal Sampler
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
REL	recommended exposure limit
RfD	reference doses
RG	risk groupings
RH	relative humidity
rms	root mean square
RPE	respiratory protective equipment
RPM	respirable particulate matter
rpm	rotations/revs per minute
S	power flux density
SA	specific absorption
SAD	seasonal affective disorder
SAR	specific absorption rate
SBS	sick building syndrome
SCBA	self-contained breathing apparatus
SCOEL	Scientific Committee on Occupational Exposure Limits
SDS	safety data sheet (previously called MSDS—material safety data sheet)
sec or s	second (time)
SEGs	similar exposed groups
SEM	scanning electron microscope
Sen	Respiratory Sensitiser
SI	International System of Units
SIMPED	Safety in Mines Research Establishment
Sk	Skin
Sk:Sen	Skin Sensitiser
SLC_{80}	sound level conversion valid for 80% of the wears
SMF	synthetic mineral fibres
SMR	standardised mortality ratio
STEL	short-term exposure limit
Sv	sievert
SWA	Safe Work Australia
T	tesla
$T^{1/2}$	radiological half-life
T_a	air temperature
TCA	trichloroacetic acid
TCE	trichloroethylene
TEM	transmission electron microscope
T_g	globe temperature
TI	tolerable intakes of chemicals
TLD	thermoluminescent dosimeter
TLV®	threshold limit value (ACGIH®)
T_{nwb}	natural wet bulb temperature

TSA	tryptic soy agar
TWA	time-weighted average
TWL	thermal work limit
UCL	upper confidence limit
UKAEA	United Kingdom Atomic Energy Association
USEPA	United States Environmental Protection Agency
U_{SG}	specific gravity of urine
UV	ultraviolet
UV-A	wavelengths 315–400 nm and frequencies around 10^{14} Hz
UV-B	wavelengths 280–315 nm and frequencies around 10^{15} Hz
UV-C	wavelengths 100–280 nm and frequencies around 10^{16} Hz
V/m	volts per metre
vCJD	variant CJD
VDV	vibration dose value
VOC	volatile organic compound
VWF	vibration white finger
W	watt (equivalent to J/sec)
WBGT	wet bulb globe temperature
WEL	workplace exposure limit
WES	workplace exposure standard
WHO	World Health Organization
WHS	workplace health and safety
w_R	radiation weighting factors
ZPP	zinc protoporphyrins
β	small spatial angle
μg	microgram (10^{-6} g)
μg/g	micrograms per gram
μg/L	micrograms per litre
μg/dl	micrograms per decilitre
μg/m^3	micrograms (10^{-6} g) per cubic metre
μGy	microgray
μm	micrometre
μmol/L	micromoles per litre
μPa	micropascal
μSv	microsievert
μT	microtesla
Φ	luminous flux
ω_R	radiation-weighting factor
ω_T	tissue-weighting factor
v	speed

1. The hazardous work environment:

The occupational hygiene challenge

Charles Steer and Caroline Langley

1.1 INTRODUCTION

Occupational hygiene is a profession grounded in science and engineering, but also requiring good communications skills, dedicated to achieving healthy workplaces. Its focus is to eliminate or, if that is not practical, to control chemical, physical or biological hazards. These hazards include hazardous chemicals, dusts, gases, vapours, mists, smokes, fumes, fibres, noise, vibration, heat and cold, ionising and non-ionising radiation, and biological hazards such as mould, fungi, bacteria and viruses.

A key characteristic of many workplace health hazards is their slow and insidious effect on health, resulting in a toll of worker illness and death that greatly exceeds the number of traumatic workplace injuries and fatalities. This is not to understate the importance of traumatic injuries and their impact. However, there is unrecognised and significant disease in our community arising from exposure at work to largely known hazards, that we can and should control.

While it would be ideal to eliminate rather than control these hazards, it is often not practical. For example, elimination of dust when mining an ore and using chemicals for which there is no safer substitute. The examples are almost endless.

Nearly all workplace activity and the associated workplace health hazards involves some aspect of occupational hygiene practice. The preventative approach of occupational hygiene, namely interventions made to the work and work environment, rather than the worker, are responsible for a large proportion of improvements in worker health. In order to be effective, occupational hygienists need a detailed understanding of the nature of hazards in the workplace, how these hazards arise and the actual extent of workers' exposure to them. They also require a sound knowledge of the risks to health which arise from exposure to each hazard, how those risks relate to exposure levels and the means to mitigate the risks.

This chapter presents an overview of procedures for workplace health investigations using the occupational hygiene principles of anticipation, recognition, evaluation and control of workplace hazards. It also lays out a framework for considering all the topics covered in this book.

This book is aimed as a general primer for occupational hygienists as well as those in other relevant disciplines who work together to achieve a healthy workplace. Figure 1.1 sets out the range of disciplines that may be involved (adapted from Harden et al, 2015).

Although the material in this book has its origins in Australia, it is also generally applicable to workplaces in the Asia-Pacific region.

1.2 HISTORICAL BACKGROUND

It is clear that humans' efforts to feed ourselves and eventually use our environment to create and build civilisations are intrinsically connected to health hazards that arise from our activities. The first mention of occupational disease is credited to Hippocrates (460–370 BCE), who documented lead poisoning in miners and metallurgists. Pliny the Elder may have been the first to document protective equipment when he noted in around 50 CE that animal bladders were used to prevent inhalation of dust and lead fumes (Blunt et al., 2011).

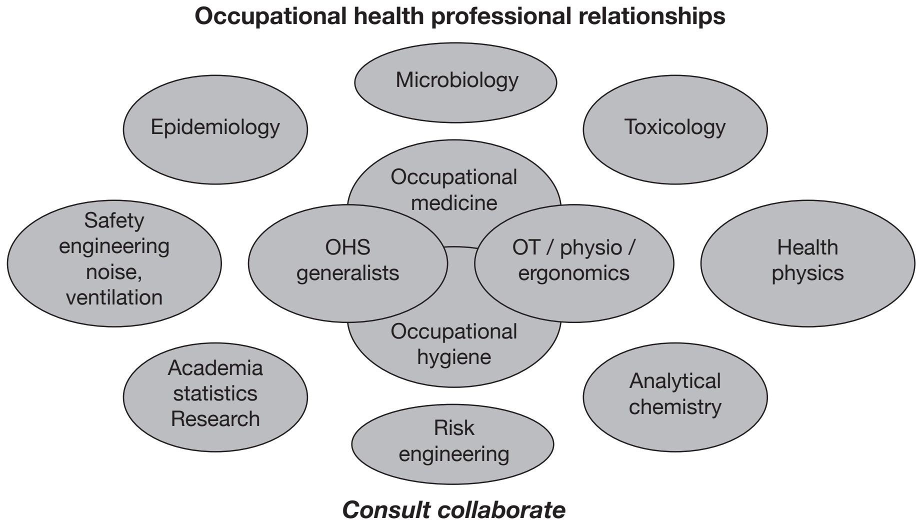

Figure 1.1 The interrelationship of occupational health and safety professions
Source: Adapted from Harden et al. (2015).

Very little occupational disease was recorded until after medieval times. Georgius Agricola described mining, smelting and refining in *De Re Metallica* (1556), including diseases and accidents, as well as the need for ventilation. Paracelsus, the medieval physician often described as the 'father of toxicology', described miners' respiratory diseases in 1567, and is said to have stated that, 'All substances are poisons . . . the right dose differentiates a poison and a remedy.' In 1700, Bernadino Ramazzini, the 'father of occupational medicine', published a book on the diseases of workers and introduced the question, 'What trade are you?'

From the late 1700s, the first Industrial Revolution accelerated workplace injuries and illness as new trades and industries such as mining and associated steam-powered factories emerged on an unprecedented scale. Awareness of workplace hazards was low or non-existent. Many who survived physical injury or escaped death in the mines became ill from dust diseases. In mines, mills and factories, workers—including children as young as six—faced injury or death from machinery and work practices designed for output, not worker health and safety. Some factory and mill owners took account of the general safety, health and welfare of their workers, but these were in the minority. Legislation in western countries became the driver for improvements to workplace health and safety but change was slow. It was not until 1833 that the first real labour laws and the Factory Inspectorate were established in the United Kingdom; this was followed by the *Coal Mines Act* in 1842.

With the development of chemical-based industries in the late nineteenth and early twentieth centuries, many new occupational diseases emerged associated with exposure to chemicals; some of them continued unchecked until relatively recent times, despite readily available evidence of the hazards. Occupational diseases commonly associated with mining and quarrying (pneumoconiosis or dust diseases), tunnelling (silicosis), fur carroting to make felt (mercury poisoning), yarn and fabric manufacture and textile weaving (byssinosis, scrotal cancer), potteries (silicosis), metal casting and finishing (silicosis and metal fume fever), chimney sweeping (scrotal cancer), matchstick manufacture ('phossy' jaw or bone necrosis from oxide of phosphorus exposure) and bridge building (caisson disease) became accepted as ordinary risks of these jobs. While many of these industries and issues have disappeared, some of these diseases remain—such as silicosis, pneumoconiosis and metal fume fever even though the causes and controls are well known.

While Georgius Agricola, Bernadino Ramazzini and Charles Thackrah made astute observations about the importance of understanding a worker's job or trade so as to assess the impacts on health, occupational hygiene as we know it made no real advances until World War I. Pioneering work done by Dr Alice Hamilton (1943) and others in the early twentieth century brought industrial disease—particularly in the war industries such as munitions—to the attention of legislators, employers and workers in the United States and Britain.

In Australia, factory and mining work health and safety laws followed the UK example, but were not enacted by the states until the late nineteenth and early twentieth centuries. Australian social reform, including an emerging labour movement and a federal arbitration system established in 1905, further improved protections for workers, including children (Damousi, Rubenstein and Tomsic, 2014).

Like its UK predecessors, early Australian legislation was industry based, with targeted prescriptive regulations to control specific hazards. These regulations set out complex requirements that were difficult to comply with and that were, by their nature, incomplete. Furthermore, with the rapid advancement of industry, including chemical manufacturing and defence, health and safety legislation was always lagging in terms of technical, medical and epidemiological knowledge.

Occupational health and safety (OHS) legislation fundamentally changed in the 1970s and 1980s in Australia, as so called Robens-style regulation took over, with its central tenets of overarching legislation featuring self-regulation and the statutory duty of employers to consult employees and to ensure their health and safety at work (Australian National University, REGNET, 2017). This approach marked the beginning of codes of practice and specific sections in the regulations to provide guidance. Australia has been moving towards consistent harmonised OHS legislation between all states and territories, but this has not yet been fully achieved. The harmonised legislation sets out clear responsibilities and requirements for employers to eliminate risks to health and safety so far as is reasonably practicable and, if not reasonably practicable, to minimise those risks so far as is reasonably practicable. The legislation is backed up by extensive codes of practice and other guidance material that is freely available. This rather legalistic approach effectively enshrines the basic human right of being safe and healthy at work.

The profession we now know as occupational hygiene (also called industrial hygiene in the United States, Malaysia, Indonesia and other countries) emerged after World War II in the United States and the United Kingdom. Scientists and engineers from government and industry began working and collaborating in this field in Australia in the 1960s, with the Australian Institute of Occupational Hygienists, Inc. (AIOH) being formed in 1980.

The AIOH website, <www.aioh.org.au>, provides details of the professional membership grades, activities such as conferences and training and university courses accredited by the AIOH. Courses at various levels are also available online through <www.OHLearning.com>.

1.3 THE PRESENT

In Australia, there is a sound, although not yet fully consistent, OHS legislative framework, with associated federal and state/territory regulators, a well-educated workforce and a cohort of well-trained OHS professionals including occupational hygienists. However, there are continuing challenges, as evidenced by the high rates of occupational disease outlined below in Section 1.4. Many of the 'older hazards' have disappeared, but many remain, along with new occupational health challenges. The following sets out the extensive range of health hazards that can be experienced in modern workplaces:

- *hazardous chemicals* (Chapter 2), including:
  - carcinogens such as arsenic and benzene
  - substances that are toxic to organs or organ systems, such as toluene, mercury, glutaraldehyde or ethanol
  - reproductive and teratogenic substances, such as lead
  - corrosive substances, whether acidic or alkaline, such as acid gases
  - sensitising agents, such as nickel, isocyanates and glutaraldehyde, which can affect the skin, respiratory system and gut
  - irritants such as ammonia and ozone.
- *aerosols* (Chapter 7), including:
  - airborne liquids and solid particulates, such as smokes, fumes, dusts, mists and fibres
  - mining and quarrying, construction and manufacturing dusts, such as coal, metal and wood dusts, respirable crystalline silica
  - vehicle exhaust emissions, including diesel particulate matter (DPM)
  - biologically active particulates in pharmaceutical manufacturing, bioaerosols from cutting fluids
  - nanoparticles in pharmaceutical and other manufacturing processes
  - acid fumes from electroplating and anodising in manufacturing and defence-related industries
  - metal fumes from welding, smelting, refining, soldering and cutting (Chapter 8)
  - acid mists from electro-refining
  - hydrocarbon mists from spray painting
  - fibres from manufacture and handling of human-made fibre products, asbestos removal, cotton and paper manufacture
  - pesticides, including insecticides and herbicides, and grain dusts found in agriculture
  - airborne contaminants from chemical manufacture, process plants, mining, construction and emergency services.
- *gases and vapours* (Chapter 9) from almost all work settings, including:
  - oxides of nitrogen, carbon dioxide, carbon monoxide, cyanides from internal combustion engines in mining, logistics and construction
  - ozone from welding
  - hydrocarbons from petroleum refining and storage, solvent degreasing
  - anaesthetic gases and other biologically active vapours in medical and veterinary settings

  - hazardous and irritant chemicals such as formaldehyde from building materials in offices
  - asphyxiants such as nitrogen, carbon monoxide and refrigerants.
- *noise and vibration* (Chapter 12) from almost all industries, including manufacturing, agriculture, defence, construction, mining, tunnelling and logistics.
- *thermal (heat or cold) stress* (Chapter 14) arising from outdoor and cold store work
- *biological hazards* (Chapter 16), including:
  - fungi and mould in the built environment, particularly in warm humid environments
  - biological hazards, moulds and fungi in agriculture
  - bacteria such as *Legionella pneumophila* in excess concentrations in potable water and cooling towers
  - zoonoses, including glanders, anthrax, Q fever, bird flu, lyssavirus, Hendra virus and so on in animal husbandry
  - biological hazards in health and medical settings, including accidental contact with blood and body fluids.
- *potable water quality*, where sites provide the drinking water supply, such as remote mine sites; this includes bacterial, chemical and physical quality (such as turbidity) (NHMRC and NRMMC, 2018; NHMRC, 2011).
- *ionising and non-ionising radiation* (Chapter 13) in a wide variety of industries, including mining, power, manufacturing, medical diagnostics, research and defence.
- *ultraviolet radiation* exposure is a hazard for all outdoor workers as well as from welding processes and specialist equipment.

Occupational hazards such as those listed above can exist separately or together in a range of industries and workplaces, including construction, manufacturing, defence, research, health, mining, agriculture and even office or retail environments. Although the body of knowledge on these hazards and their control is now extensive, some hazards are underestimated, some are ignored and yet others have re-emerged due to complacency. A salient example is the control of coal mine dust: the prevalence of coal workers' pneumoconiosis was as high as 27 per cent in Australia before World War II (Moore and Badham, 1931) and 16 per cent in 1948 (Glick, 1968). Unfortunately, there have been recent recurrences of pneumoconiosis in Queensland (Parliament of Australia, 2017) as well as in the United States (Blackley, Halldin and Laney, 2018), demonstrating the importance of maintaining controls and understanding the hazard.

The recent re-emergence of silicosis from working with manufactured (artificial or composite) stone kitchen benches is an example of a long-standing hazard not being recognised in a new industry (Thoracic Society of Australia and New Zealand, 2017).

A further complication is the proliferation of small workplaces, including the so-called 'gig economy', or piecemeal work where there is no union or organisational support or accumulated knowledge, almost certainly resulting in vulnerable workers. Vulnerability increases where the workforce includes migrants, disabled workers, non-English speakers and informal workers.

The challenge is significant for occupational hygienists and other professionals to provide good guidance, especially for hazards that cannot be seen, heard, felt or smelt, and that can produce health effects that may not become apparent for many years.

1.4 THE SERIOUS PROBLEM OF UNDER-ESTIMATION OF OCCUPATIONALLY RELATED DISEASE

Is work-related ill-health important enough to deserve the attention it now receives? The last 30 years in Australia have witnessed an expansion of occupational health laws and regulations, with greater government administration and new inspectorates. There are many technical guides, numerous training programs and expanded legal services. The numbers of OHS professionals and research programs are growing. But are workplace hazards—from chemicals to conditions—really detrimental to our health? After all, there are relatively few ill people in any given workplace and our workers' compensation systems report relatively few cases of occupational disease. When a disaster like a rail crash or an explosion occurs, it is easy to count fatalities. In contrast, occupational disease resulting from exposure to physical, chemical or biological agents may take years or decades to develop, so its causes are often not immediately apparent. Many similar illnesses are also the result of lifestyle or social conditions. Workers move away or change jobs or retire. A sick worker's doctor may simply be unaware of the kind of work that their patient does or has done in the past, and asking about a patient's occupation is probably unusual in typical doctor–patient interactions unless the doctor has some training in occupational health. Historical records of occupational exposures are rare, although new laws now mandate record-keeping in some cases.

Reliable data on the contributions of workplace conditions to ill-health in the community have traditionally been difficult to assemble, and this is a worldwide problem. Data on compensation for work-related ill-health is lacking, leading to a misleading impression of the true prevalence of occupational disease. Most work-related ill-health is the result not of accidents (falls, high-energy impacts, crushing or piercing injuries, etc.), but of exposure to hazardous chemicals or environmental conditions. Consider the following examples where the findings of epidemiological studies—sometimes conducted years after exposure first commenced—confirmed the need for the controls now widely demanded by law:

- *The world's worst single-event industrial disaster (with the probable exception of Chernobyl).* At Bhopal, India in 1984, the inadvertent release of methyl isocyanate gas (an intermediate of manufacturing a pesticide) killed more than 3000 people and injured some 17,000 more who lived in the chemical factory environs. Although the cause of the disaster was soon evident, its true scale was not so immediately obvious.
- *The United States' worst individual industrial accident.* Hawk's Nest Tunnel in West Virginia, built to divert a river in the early 1930s, required drilling through silica rock. As a result of inhaling the resulting dust, more than 600 men died from silicosis within two to six years. Neither the cause of the illness nor its true prevalence were obvious at the time of the work.
- *Australia's worst industrial accident.* Mining of blue asbestos at Wittenoom, Western Australia continued from 1937 to 1966. At that time, the link between asbestos fibre exposure and asbestosis, lung cancer and mesothelioma was not well defined. Workers, town residents and visitors developed these diseases over the ensuing decades and deaths are still occurring. The death toll could eventually exceed 2000. Worldwide, the death toll from asbestos exposure in the late twentieth and early twenty-first centuries could possibly reach into the millions.

A further disturbing aspect of asbestos-related disease is that the number of new mesothelioma cases continues to be high. As the first wave of deaths from exposure during mining and processing prior to 1983 declines, a second wave of disease has emerged in tradespeople and workers in asbestos buildings (ASEA, 2016). Although these exposures were much lower, far more people were exposed, resulting in continuing high numbers of mesothelioma cases and deaths. Asbestos is covered in more detail in Chapter 7.

These examples demonstrate not only that exposure to hazardous substances can cause severe ill-health or death, but that the true impact of this exposure can take years or decades to become apparent.

In the 1980s, the US National Institute for Occupational Safety and Health (NIOSH) identified the 'top ten' workplace injuries and illnesses (US Department of Health and Human Services, 1985). The list included occupational cancers, dust diseases, musculoskeletal injuries and hearing loss, and a number of other diseases still with us today (Safe Work Australia, 2017).

It is generally acknowledged (Schulte, 2005) that the burden of occupational disease is significant but under-estimated as the recording of long latency diseases is difficult and there may well be co-contributing causes.

The latest estimates of the global burden of occupational disease indicate that a significant challenge exists. In 2017, the Singapore Workplace Safety and Health Institute (Hämäläinen, Takala and Kiat, 2017) reported an estimated 2.78 million global deaths each year that could be attributed to work. This is approximately 5 per cent of total global mortalities and higher than the 2.33 million occupational fatalities reported in 2014. Contrary to the focus of effort by many workplace regulators, the institute states that 86 per cent of these work-related deaths are caused by occupational disease, compared with approximately 14 per cent of fatalities that were directly related to accidents. Globally, the most significant occupational diseases are respiratory disease, including chronic obstructive pulmonary disease, circulatory diseases and malignant neoplasms.

In the absence of any published Australian estimates and using the ratio of around ten fatal illnesses to one fatal injury, as has been derived in the world, US and NZ estimates as shown in Table 1.1, this results in an estimate of 1820 Australian illness fatalities for the year 2016 (Safe Work Australia, 2017). Although this result is an estimate, it serves to illustrate the size of the challenge.

An obvious question to consider is whether injury and illness rates will decrease in future as workplaces become better controlled.

On the positive side:

- Australia's injury fatality rates have been falling—from 259 in 2003 to 185 in 2017 (Safe Work Australia, 2017)—suggesting improved management commitment, awareness, design and operational improvements that are likely flowing to health hazard control.
- Australia is 'exporting' more dangerous work—for example, in manufacturing and processing industries. This is a positive for injury and illness statistics in Australia; however, it may be compounding problems elsewhere and could be deeply misleading in terms of human suffering.
- Legislation has improved (for example, banning asbestos, the use of quartz in grit blasting) along with more comprehensive codes of practice and consequent awareness.

Table 1.1 Summary of estimated fatalities by illness and accident in various jurisdictions

Jurisdiction	Estimated annual illness and accident fatalities	Ratio of fatalities from illness compared with injury
Worldwide	2.4 million deaths linked to work-related illnesses 0.38 million fatal injuries (Hämäläinen, Takala and Kiat, 2017)	6
United States	26,000 to 72,000 linked to work-related illnesses 6200 fatal injuries (Steenland et al., 2003); estimated annual cost US$128–155 billion	9
Great Britain	13,000 deaths related to work-related illness primarily linked to chemicals and dust 144 fatal injuries (HSE, 2016/17); estimated cost £9.7 billion for illness and £5.3 billion for injury	99
New Zealand	600–900 deaths related to work-related illness (WorkSafe NZ 2017) 73 fatal injuries (WorkSafe NZ 2017)	Approximately 11

- Smoking rates have declined, decreasing the chance of synergistic health effects.
- Engineering control technology has improved—for example, large-scale dust and vapour control, noise control, hand-held tools with local exhaust ventilation.
- Environmental legislation has become more stringent, coincidentally causing improvements to worker health and safety—for example, vehicle emission standards, environmental dust and noise requirements.

On the negative side:

- The so-called ‘gig’ economy is growing, along with increasing numbers of small to very small businesses that have limited resources and more workers in multiple transient jobs.
- New advances in technology such as nanomaterials may be outpacing health research.
- There have been reductions in the numbers of specialists employed by regulators, including occupational hygienists, occupational physicians and occupational health nurses.
- There are large areas of industry that have not experienced significant exposure to occupational hygiene principles and application, such as construction, manufacturing, agriculture and health care. This is now changing in some sectors—for example, in tunnelling, where high-level occupational hygiene expertise is starting to be applied. This is, however, by no means universal. In 2017, Australia had approximately

1.17 million persons employed in construction, 885,000 in manufacturing, 325,000 in agriculture, forestry and fishing and 1.66 million in health care and social assistance. This compares with mining, which has a relatively mature occupational hygiene culture and employed around 216,000 persons (Parliament of Australia, 2018).

- It is estimated that around 40 per cent of those in the Australian workforce are still exposed to carcinogens in their current job roles (Carey et al., 2014; Carey et al., 2017).

Future challenges include:

- The need to keep manufacturing facilities and process plants up to date to reduce noise, chemical and other exposures.
- The need for companies to ensure that lessons learnt from older facilities are applied when building new ones, including retaining a 'corporate memory'. It is also important that company return on investment considerations are made in the light of cost-effective health and safety options. Occupational hygienist need to argue for the overall benefit of higher order control measures—for example, design and engineering solutions for noise rather than supply of ear plugs.

The limitations of current workers' compensation data systems for recording and estimating occupational illness are recognised. Work-related illness is a continuing burden, with appreciable cost-shifting of long latency disease into the public health system in Australia and other countries.

1.5 THE OCCUPATIONAL EXPOSURE RISK-MANAGEMENT PROCESS

The classic occupational hygiene process involves:

- *anticipation* of problems—a vital skill; while this usually requires considerable experience, assistance is now provided by abundant resources, including safety data sheets (SDS), various databases and websites
- *recognition*—knowing the hazards and the processes by which they may affect health or identifying them through adverse health effects
- *evaluation*—measuring exposures, comparing against standards, assessing risk
- *control*—providing contaminant or hazard control. The level of protection required is based on knowledge of the toxic or other adverse effects produced by known quantitative exposures to the hazard.

These steps may need to be added to in more complex workplaces, as depicted in Figure 1.2, where it is important to characterise the hazard and, if required, carry out monitoring. Once controls are in place, it is essential to carry out regular reviews of their continuing effectiveness.

Figure 1.3 provides more detail on the major risk assessment components. These are explained in the following sections. It is important to note that this section is a summary only. The reader is encouraged to refer to the references as well as the later chapters in this book to obtain a more detailed understanding.

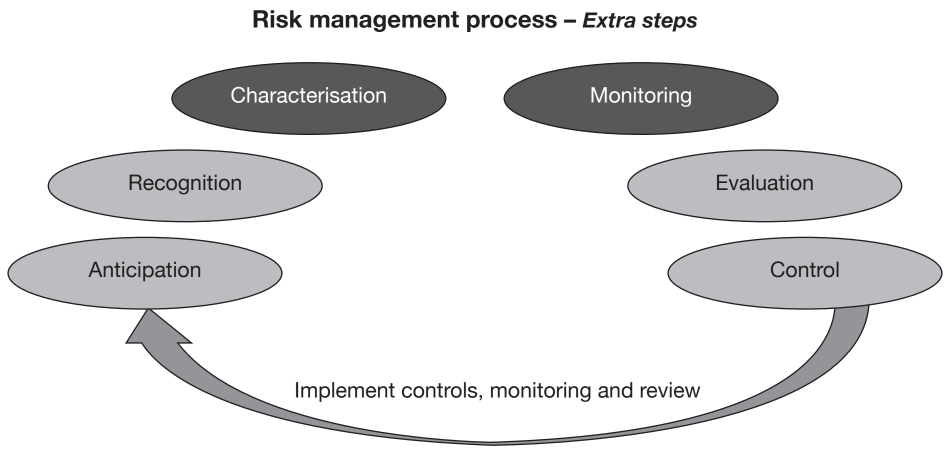

Figure 1.2 Additional steps in the risk-management process

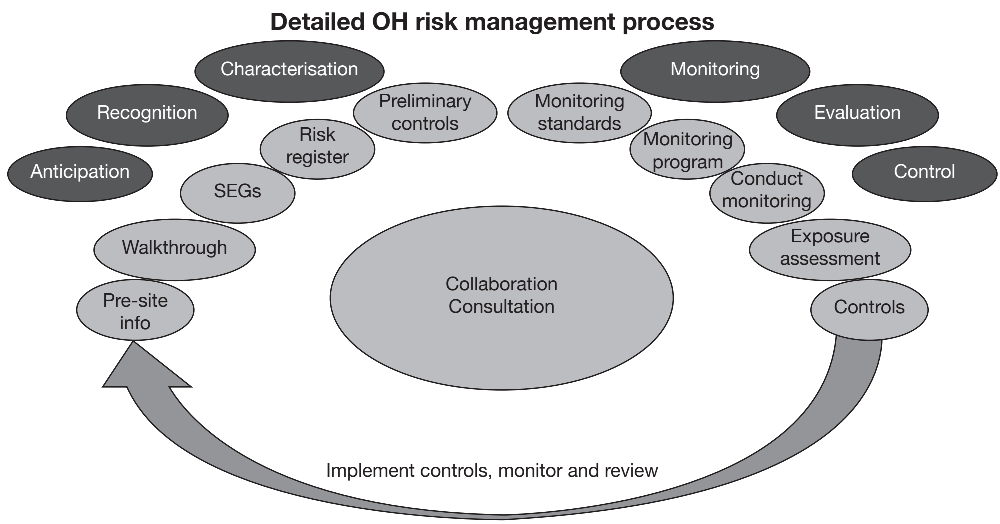

Figure 1.3 Detailed components of the occupational health risk-management process

1.5.1 ANTICIPATION

Anticipation involves identifying potential hazards before they are introduced into a workplace or before you visit the workplace. This can be undertaken using a HAZOP process, which would include collection and review of the following information:

- site plans and where specific chemicals are handled
- employee numbers and organisation
- site-specific legislation and regulations, including exposure standards
- any previous monitoring and analysis

- injury and illness records, taking into account the long-term nature of the health effects of some chemicals and physical agents, which may include any patterns of adverse health effects
- incident reports
- company standards and procedures
- SDS for hazardous chemicals. All SDS in Australia are now required to be in the Globally Harmonised System (GHS) format.

There are many work situations where an SDS is not available but the nature of the hazard(s) is well known—for example, asbestos exposure in building maintenance, wood dust exposure in small joinery workshops. In these cases, alternative information sources need to be used, such as codes of practice, guidelines and research publications.

There are other situations where the health effects are not so well known and further research will be required, possibly including using external specialist expertise.

1.5.2 *RECOGNITION*

Recognition of health hazards in the workplace is fundamental to their effective control. There are two major components in this step:

- Understanding the health effects and characteristics of the chemical, physical or biological agent.
- Being aware that the agent may hurt the worker—for example, by skin contact.

Key chemical, physical or biological characteristics include:

- The inherent toxicity or other health effects of the various physical chemical and biological agents, as set out in subsequent chapters.
- Potential exposure routes—for example, whole body, inhalation, ingestion or absorption through the skin, eyes or aurally; these are set out in subsequent chapters covering specific health-affecting agents.
- Whether the effects are acute or chronic.

With regard to chemicals and some biological agents it could include whether they are sensitisers, irritants, asphyxiants, target organ affecting, carcinogenic, corrosive to the skin or eyes, gut or respiratory tract, and whether they may react with other chemicals to produce new hazards. The physical form of the agents is also important—for example, are they aerosols, solids, liquid lipophilic or lipophobic, acidic or alkaline?

Recognition of hazards may be complicated in the following ways:

- Many health hazards cannot be seen, heard, smelt or felt.
- Some hazards, such as non-ionising radiation, are not well understood by workers or employers.
- A chemical may have no adequate warning properties such as odour.
- Workers do not know what their exposure is.
- Workers and employers may accept exposures as an unavoidable part of the job.

A *site walk-through* (or walk-through inspection or survey) is a critical step in any assessment. It is the opportunity to integrate the knowledge of the hazard with the way it is used or experienced in the workplace to gain insights into how workers can be affected.

Exposures can occur from handling, processing, transporting, packaging and storage of raw materials to by-products, intermediates, waste and finished materials. Exposure may be routine, occur intermittently (e.g. during a shutdown), be due to a non-standard operation or occur only in an emergency.

Industries that typically give rise to occupational health hazards are widespread (US National Library of Medicine, 2019). They include major employment sectors in Australia and Asia, such as the following:

- *Agriculture, fishing and farming*. These sectors involve a wide variety of planting, harvesting, crop and livestock management practices that use or produce hazardous dusts, pesticides and herbicides, and microbiological hazards associated with moulds and fungi. Dangerous gases may arise in silage pits, silos and enclosed feed sheds. Ultraviolet radiation, along with thermal stress, tool and vehicle vibration and noise, may require controls. In animal husbandry, parasites and other zoonotic agents may be present, as well as immunological sensitisers. Fin and shellfish processing involves exposure to aerosolised proteins that are immunological sensitisers. There is also extensive wet work and noise.
- *Food processing and packaging industries*. These may expose workers to zoonotic agents, wet work, toxic, corrosive, irritant or sensitising chemicals, noise and vibration, organic dusts and thermal stress. Food flavours, colourants and additives used in concentrated form in large quantities may be irritants or sensitising agents.
- *Health industries*. These industries, including hospitals, may produce a wide range of hazards, including cytotoxic, sensitising and corrosive chemicals, equipment generating ionising radiation, unsealed radioactive materials and noise. Anaesthetic administration in hospitals and veterinary clinics may pose a risk.
- *Building and construction*. This industry involves potential exposure to dusts, including crystalline silica, wood dust, asbestos and human-made mineral fibres, metal fumes, paints and coatings, solvents and adhesives, cements and fillers, noise and vibration.
- *Chemical manufacturing*. Harmful or toxic gases, liquids and solids form the basis of most areas of this industry, such as oil refining, plastics manufacturing and cyanide production. Gas reactions and gassing procedures in the production of petrochemicals, the synthesis of plastics, rubbers and fuels, and catalysis, fumigation and sterilising have the potential to give rise to serious inhalation hazards.
- *Heavy and light manufacturing and processes.* Such processes, which include welding, soldering and thermal metal cutting, produce a range of potentially toxic metal fumes, and/or irritant, oxidising and asphyxiating gases from welded material, welding rods or fluxes. Industrial plating processes pose risks of skin damage, respiratory system damage from corrosive aerosols and systemic poisoning from toxic gases and aerosols. Processes involving the manufacture, bagging and pouring of powders and dry materials produce fine dust. Industrial processes using electromagnetic operations, such as large direct current metal smelters, radiofrequency induction furnaces, microwave heaters, x-ray equipment and radar signal generators, can all produce biological

effects unless equipment is properly shielded. Radio and microwave transmission towers produce significant risks in near-field radiation zones. Smelting and hot metal handling generate metal fumes, gases and vapours from decomposition of moulds, heat and radiant energy, noise and light. Abrasive blasting typically uses steel shot, garnet, smelter (e.g. copper) slag, staurolite and heavy mineral sands (ilmenite), and produces much fine dust and very high noise levels. Vapour degreasing is a widely used industrial process posing hazards from vapour inhalation and skin and eye contact. Reinforced plastics usage may create exposures arising from various resins and human-made mineral fibres to potent skin and respiratory irritant and sensitising agents, corrosive and toxic substances. Painting and coating cover a wide number of processes using organic and inorganic powder suspensions and solutions to spray, brush and roller-coat, creating exposure to aerosols of organic materials as well as a range of solvent vapours, toxic metals, severe irritants and respiratory sensitisers. Drying ovens are widely used in manufacturing, art and craft, and industrial surface coating. Ovens produce vapours from solvents, lacquers, paints, cleaning agents and plastic resins, as well as combustion gases from fuels. Nanotechnology engineering leads to exposure to superfine particles in a wide array of processes involved in the manufacturing of products from cosmetics and fabrics to paints.
- *Mining and quarrying.* Processes in these industries may create exposures to dusts, radioactive gases, vehicle emissions, including diesel exhaust emissions, noise, vibration, risks of asphyxiation, poisoning by various gases, and injury or death from explosions.
- *Transport and logistics*. These operations, including road and rail, shipping, aircraft and warehousing, involve exposures from the materials and goods being handled, as well as dusts, vapours and solvents, vehicle exhaust, noise and vibration.
- *Laboratories.* These are locations where exposure to toxic, irritant, sensitising, corrosive or mutagenic chemicals may occur in novel operations. Physical hazards arising from equipment generating ionising and non-ionising radiation and lasers are common. Unsealed radioactive materials and biological agents may also be in use.
- *Enclosed buildings and the built environment*. Such environments, including office and retail environments, may produce hazards from volatile organic compounds arising from office equipment such as printers and photocopiers, off-gassing by building products, carbon dioxide build-up from poorly ventilated buildings and biological hazards (moulds and fungi).

Information gathered during a walk through survey could include:

- detailed site and process information and any problems (e.g. symptoms) experienced, including discussions with management, supervisors and workers. Workers may often have specific knowledge of the idiosyncrasies of machinery (and operators), processes and how well the process works or doesn't work, and non-routine operations.
- the materials used or handled and any difficulties experienced—again by specific questions
- the type and extent of worker training
- the number of workers involved and shift arrangements

- evidence of reactions, any material transformations (generated substances), by-products, intermediates and wastes. The work process itself may generate a hazard from an apparently innocuous precursor material.
- exposure times of directly involved employees as well as bystanders
- existing engineering controls that are in place, and whether they work as expected
- housekeeping at the site (e.g. spillages and cleaning methods)
- visible conditions at the site (any dusts, mists, smoke, fume, odours, deposits of material)
- possible routes of entry (inhalation, skin, ingestion, injection)
- personal protective equipment (PPE) availability, use and maintenance
- processes that expose workers to noise, vibration, heat, cold or ionising or non-ionising radiation
- processes that may contact and affect the skin.

1.5.3 PRELIMINARY CONTROLS

This is an optional step, depending on circumstances. A walk-through survey or a preliminary medical examination may identify urgent issues that require immediate controls. In these circumstances, it is important not to wait until a formal process is completed before acting to improve worker health protection.

1.5.4 CHARACTERISATION

This process involves characterising the workplace, workforce and exposures to health-affecting agents in the workplace (AIHA, 2018; Jahn, Bullock and Ignacio, 2015). Steps include:

- Use information gathered in the earlier stages to develop similar exposure groups (SEGs). An SEG is defined as a group of employees (two or more) similarly exposed to health-affecting agents. SEG development will required consultation with supervisory and workplace representatives. Note that workers may be exposed to more than one hazard at a time.
- Next, develop a site-specific risk register (Firth, Van Zanton and Tiernan, 2006) where the health risks of physical, chemical or biological agents are assessed for individual SEGs. A risk register will include existing controls, calculated inherent and residual risks and proposed controls. It provides a summary of the status of occupational health management at any workplace, and can be used to further develop action plans for additional controls and provide input into determining any medical assessment requirements. Members of the workforce, supervisory personnel and subject-matter experts need to be consulted during the development of the risk register.

1.5.5 MONITORING

Monitoring is a key aspect of the practice of occupational hygiene, and is covered in some detail in subsequent chapters. The following is a summary of the ways in which monitoring fits into the occupational exposure risk-management process.

- Once SEGs have been selected and a risk register has been developed, it is necessary to determine whether a more detailed exposure assessment is required. The main basis for this assessment is often workplace monitoring.
- The key criteria for monitoring is whether the exposure is likely to exceed an exposure standard or whether there is uncertainty about whether it is likely to affect health. Provisos include practicality and whether an appropriate occupational exposure limit (OEL) exists for the chemical, physical or biological agent.
- An optimal occupational hygiene monitoring program will provide statistically valid monitoring, where appropriate, of health-affecting agents (Grantham and Firth, 2013; Liedel, Busch and Lynch, 1977). The general requirements are sufficient sample numbers, representative sampling times within a shift and random sampling dates over a sufficient time period that takes account of seasonal variations, as well as day, night and weekend shifts as appropriate. Some monitoring may be programmed—for example, campaign monitoring of specific agents during a plant shutdown or for batch processes. There are various options in relation to monitoring equipment and techniques, including passive or active monitoring, direct reading instruments and so on (Chapters 7 and 9).
- It is generally preferable to carry out personal monitoring, but monitoring can include area, surface, biological and specific physical and biological agents, as set out in Chapter 3 as well as Chapters 7 to 16. There is a so-called hierarchy of exposure criteria (Laszcz-Davis, Maier and Perkins, 2014; Jahn, Bullock and Ignacio, 2015), with their foundation ranging from quantitative to more qualitative (see section 3.11.1: Control banding in Chapter 3).
- Exposure standards may need to be adjusted according to shift length and other factors (see AIOH, 2016; Standards Australia, 2005). Attention should also be paid to additive exposures, synergism, potentiation and ototoxic effects (Chapters 3 and 12).
- Monitoring must take account of the precision and accuracy of the sampling and analytical method if applicable. In all cases, monitoring equipment must be appropriately calibrated and maintained. Monitoring is of no value unless the results can be assured and potential errors understood.
- Wherever possible, analysis of samples must be undertaken by a laboratory accredited for the test(s) being conducted, and reported in accordance with recognised standards.
- Monitoring needs to be designed and carried out by appropriately qualified and resourced personnel with full support from site management. Expertise will depend on the agents monitored, and includes occupational hygienists for design and monitoring; it may also include analytical chemists, microbiologists, ergonomists and acoustic engineers.

- All monitoring results should be reported and made available to the workforce except where inappropriate for privacy reasons (e.g. personal biological monitoring). These results should be reported to the individual only.
- A key document summarising the monitoring program will be a SEG matrix listing health-affecting agents; a partial example is set out in Table 1.2 for a mine.

Table 1.2 Example of part of a SEG matrix

				Number of samples / measurements required					
SEG number	**SEG name**	**Typical tasks**	**Number of employees in SEG**	**Inhalable dust**	**Respirable crystalline silica**	**Welding fume**	**Thermal stress**	**Noise**	**Legionella/potable water**
1	Dragline	Conduct dragline operations – operate auxiliary equipment etc.	14	11	11	Not measured	Targeted summer	8	Potable on plant Legionella in workshop
3	Field maintenance	Field maintenance of mobile plant	55	18	18	9 (opportunity basis)	Targeted summer	12	

In some circumstances, alternatives to workplace monitoring may be used, including:

- mathematical modelling (Keil and Simmons, 2009), ranging from simple models to computational fluid dynamics. This can be useful for situations including:
  - estimates during the design stage of a process or review of engineering design options for a control
  - scenario analysis
  - very large sites with many variations across processes resulting in excessive demands on monitoring and analytical resources
  - where convenient methods for monitoring are not available.
- control banding, which moves directly to the evaluation stage when monitoring data and/or occupational exposure standards may not be available (Chapter 3).

1.5.6 EVALUATION

Having measured an exposure, it is necessary to evaluate the risk associated with the hazard. This evaluation step is critical for answering the following questions:

- Is the particular risk from exposure acceptable?
- Does its existing level meet regulatory requirements?
- Will it need controlling to make it healthy and safe?
- Are there special controls for this hazard?
- How much control is needed?
- What is the most effective control mechanism for this risk?

There are, of course, many situations where evaluation will show that no further action is needed; however, a more formal and systematic approach is often required to evaluate a measured exposure.

Risks can be evaluated using a variety of methods, depending on circumstances. In the case of toxic chemicals, there are two components in the evaluation: the exposure profile and toxicity. The resulting health risk can be described as a combination of exposure and toxicity (Jahn, Bullock and Ignacio, 2015). This can be developed further to produce risk matrices to provide a qualitative risk estimate (ICMM, 2016; Jahn, Bullock and Ignacio, 2015) (see Chapter 7). These matrices are generally based on likelihood (exposure) and consequence (from toxicity). It is this integration of the exposure profile with the toxicity or other health effect that provides the overall risk. The resultant risk can then be used to revise the risk assessment in the risk register.

A range of techniques can be used as part of the risk evaluation or legal compliance assessment processes:

- If an OEL exists and statistically valid monitoring has been carried out, then formal exposure assessment methodologies can be used. These are most often used for some chemicals, aerosols, gases, vapours and noise, and are set out in various publications (BOHS and NVvA, 2011; Grantham and Firth, 2013; Jahn, Bullock and Ignacio, 2015). Techniques used include Bayesian statistics (Hewett et al., 2006) for smaller sample sizes as well as tools such as the IHStat program (AIHA, 2014). The measured exposure can then be used to provide guidance on compliance with legislation (Grantham and Firth, 2013, Chapter 3) as well as for further monitoring and controls (Jahn, Bullock and Ignacio, 2015).
- Specific risk assessment methodologies may also be used for biological monitoring, heat, vibration and radiation as set out in the relevant chapters of this book. More qualitative techniques will need to be used for monitoring such as surface wipes.
- For more straightforward workplaces simplified risk management strategies may be used (Firth et al, 2006).
- Mathematical modelling can also be used to generate an exposure profile.
- Once the exposure assessment has been completed, it needs to be considered in the context of the likelihood of the consequence—that is, the health effect. The interplay between these two components, shown using a risk matrix, will result in an assessed risk rating ranging from low to high (or catastrophic). The interpretation of the

implications of the risk rating will often require professional judgement in terms of an appreciation of the challenge of managing that particular workplace exposure. For example, one scenario may be a likely exposure (at the OEL) to an irritant such as ammonia compared with an exposure at less than 10 per cent of the occupational exposure limit of a probable human carcinogen. The risk rating may be the same according to the health risk matrix, but its management—including risk communication—will be quite different. A typical 5x5 health risk matrix is set out in Table 1.3.

Table 1.3 Example of a health risk matrix

	Consequence				
Likelihood	**1 Minor**	**2 Medium**	**3 Serious**	**4 Major**	**5 Catastrophic**
A Almost certain	Moderate	High	Critical	Critical	Critical
B Likely	Moderate	High	High	Critical	Critical
C Possible	Low	Moderate	High	High	Critical
D Unlikely	Low	Low	Moderate	High	High
E Rare	Low	Low	Moderate	Moderate	High

Likelihood or probability may be described in the context of health, as exposure to a ratio of the OEL – for example, 'Almost certain—frequent daily exposure at 10 × OEL'. Consequences may be described in the context of a health outcome—for example, 'Serious—severe reversible health effects of concern that typically would result in a lost-time illness; can include acute/short-term effects associated with extreme temperature or some infectious diseases'. Organisations may have varying thresholds and definitions for each of the categories of consequence and likelihood in the context of health.

Together, the descriptions of consequence and likelihood are used to describe the possible outcome if the event occurred. This in turn provides the risk rating from 'low' risk through to 'critical' risk. The risk rating will determine the action required, timelines for this action, management accountability and so on. For example, 'low' risk may be managed in an organisation by the adoption of routine procedures, whereas 'critical' risk would require the attention of the chief executive officer along with implementation of a detailed plan of action to reduce the risk to an acceptable level.

- The risk evaluation will inform the controls to be used, as set out in the next section, and will also signal other processes such as updating the risk register.
- In circumstances where the OEL is not known, control or hazard banding (NIOSH, 2018) can be used. This technique has a much higher degree of uncertainty, and exhibits user and model variability (Van Tongeren, 2014); however, it may be the only practical way to carry out an assessment. The outcome in this methodology is not a number; rather, it moves to the next stage of guidance on controls.

1.5.7 CONTROLS

Control remains the least understood and often the most poorly implemented component of the risk management process. Establishing controls is, quite simply, how to protect the employee from that hazard. Controls are more fully covered in Chapter 4. The following are some key aspects.

- The process of developing controls will require input from a range of employees and subject experts, ranging from occupational physicians to engineers depending on the hazard (e.g. it may require an engineering control such as ventilation, or vaccination to induce immunity). While OHS practitioners may not be required to design complex controls such as a complete ventilation system, a broad understanding of these processes is useful.
- Controls need to follow the prioritising framework known as the 'hierarchy of control' (Chapter 4).
- The recommended controls must be assessed against the regulatory requirement to control risk so far as is reasonably practicable.
- Selecting the correct type and level of control requires not only knowledge of the hazard, exposure risk and route of entry, but also of how much control is needed, the comparative effectiveness of different control processes, maintenance and testing procedures, user preferences and social impacts. The process also requires consideration of costs. Tools are available to assess the business value of implementing controls (AIHA, 2008; Jahn, Bullock and Ignacio, 2015).
- There may be specific regulatory requirements—for example, mining inspectorates have specific regulatory workplace exposure standards for inhalable and respirable dust in mines and detailed medical surveillance requirements for lead workers.
- The evaluation process can also be used to eliminate or control hazards in the design phase and as part of change management. This is a powerful prevention tool when used.
- The recommended controls can form part of any site planning process, leading to management commitment to prioritise, resource and implement controls.
- The implementation of controls is fundamental to the elimination or control of health-affecting agents. There is no point in monitoring and evaluating hazards if controls are not implemented.
- The management document for controls will be the health action plan, which will set out responsibilities and key performance indicators.

1.5.8 REVIEW

Controls should follow a continuous improvement process with reviews of all of the major elements of the occupational health management framework including SEGs, the risk register, the monitoring program, monitoring standards, medical surveillance and so on. The frequency of reviews will vary depending on the element of the occupational health management framework. The system may also include audits.

It would be beneficial for the overall occupational health management framework to fit into an occupational health and safety (OHS) management system such as those described in AS/NZS 4801 and ISO45001. The AIOH's Occupational Hygiene Monitoring and Compliance Strategies (Grantham and Firth, 2013) also provide a helpful chart (11.1) laying out the process for compliance monitoring to meet Australian harmonised OHS legislation. However, as outlined above, exposure control is broader than just compliance monitoring.

There are many elements that make up a comprehensive occupational health-management framework. It can be a complex task bringing all these aspects together. A sample occupational health-management framework is set out in Table 1.4. Review frequencies can be set by a company's own risk assessment or by specific legislative requirements if they exist.

Table 1.4 Sample occupational health-management framework

Key health-management documents	**Components**
Health science summary	May include legislative, data, carcinogen and SEG review.
Medical monitoring summary	May include medical monitoring data and health awareness information.
Monitoring schedule	Sets out health-affecting agents to be monitored or assessed, frequency and sample numbers. Drawn from Health Science Summary
Health action plan	Includes a review of progress against the plan.
Risk register	Sets out risks for major health-affecting agents for each SEG, identifies gaps and sets out major controls using the hierarchy of controls.
Job demands manual	Sets out major physical job demands. Used by physician as an input into medicals.
Site-specific health agent management plans	Sets out management of key health-affecting agents as determined by company risk assessments or legislative requirements. Plans may include lead, radiation, asbestos, dusts, noise, health promotion, Legionella and water quality.
Standards and procedures	**Components**
Contractor management	A system to ensure that contractors carry out their work in a healthy and safe way, harmonised to company requirements.
Change management	A system to ensure that any changes affecting plant, procedures or systems, as well as procurement and design, take health effects into account—for example, Buy Quiet.

Standards and procedures	Components
Legal register	Including legislative review.
First aid	Including specific site requirements, training schedule, inspection, maintenance, etc.
Personal protective clothing and equipment standards	Includes management systems for respiratory protection, hearing protection, etc.
Records system	Includes record types, retention policy and privacy considerations.
Hazard-identification and risk-assessment procedure	Includes the company risk-assessment matrix.
Hygiene-monitoring quality assurance	Sets out quality assurance requirements for providers and internal monitoring quality assurance requirements.
Medical surveillance quality assurance	Sets out quality assurance requirements for medical assessments, equipment maintenance and assessments, including respiratory and audiometry.
Manual handling task assessment	Includes task assessment methodology and risk assessment.
Hazardous substance and dangerous goods system	Incorporates systems for bringing new chemicals on site, hazardous substance-assessment procedures, including storage and disposal. May also be major hazard facility legislative requirements.
Thermal (heat and/or cold) stress-assessment procedure	Incorporates measurement, assessment and controls.
Fitness for work	Includes fatigue and hydration management, drug and alcohol, employee assistance.
Legionella-monitoring procedure	Legionella standard operating procedure sets out monitoring strategy, schedules and control strategies.
Potable water-monitoring procedure and action plan following exceedance	Sets out monitoring strategy, schedules and control strategies.
Exposure standards	Integrates company, Australian and state exposure standards into context, taking working hours/shift and other adjustments into account.

Quality Assurance (QA)	Components
Occupational hygiene monitoring QA procedures	May include particulates, vapours, gas, noise, vibration, biological, thermal, alcohol and drugs testing.
Medical systems QA procedures	Includes monitoring equipment register.
Internal or external audits of major occupational health systems	
OH training	Training needs analysis. Review of effectiveness of training, records.
Respiratory and hearing protection FIT testing	May be quantitative or semi-quantitative.
Non-routine monitoring	**Components**
Lighting survey	
Noise contour map of fixed plant	
Electromagnetic field survey	Focus on major likely EMF sources such as sub-stations and large electric motors.
New plant assessments—e.g. noise, vibration	As per Australian and international standards.
Ventilation	Includes local exhaust ventilation such as welding exhaust ventilation and its testing frequency, supplied air from compressors as per AS1715.
Registers	**Components**
Maintenance	Site-specific maintenance relating to health-affecting agents.
Signage	Includes mandatory personal protective clothing and equipment, such as hearing protection areas, pacemakers and hearing aids (electric fields), ionising radiation, dangerous goods, confined spaces, authorised access, etc.
Monitoring equipment register	Includes both occupational hygiene and occupational medical equipment as well as calibration schedules.
Training register	Training status of all employees, reviewed as part of training needs analysis. Also includes FIT testing for respirators and hearing protection.

1.6 OTHER OCCUPATIONAL HYGIENE TOOLS

One very significant aspect of occupational hygiene is the extent of the online tools and apps available to help the occupational hygienist, health professional or workplace representative to assess the workplace and improve their skills.

Due to the dynamic nature of online tool development, it is suggested that the reader consult the web pages of major OH organisations in the first instance. These include:

- AIOH—position papers, exposure assessment spreadsheets
- AIHA—exposure-assessment strategies committee; Excel-based tools including spreadsheet applications of statistical analysis, skin permeability, basic workplace exposure assessment, IH exposure scenario tool
- BOHS—links to 'Breathe Freely' for construction and manufacturing with significant material for OH risks in these industries
- Occupational Hygiene Training Association—freely available access to a comprehensive range of occupational hygiene training courses
- UK Health and Safety Executive—codes of practice and numerous computer-based tools, including vibration and noise calculators as well as the COSHH control banding system.

There are numerous occupational hygiene apps available in areas including noise exposure, octave band analysers, thermal risk, lux meters and whole-body vibration, as well as powerful apps available from instrument manufacturers providing monitoring advice and instrument catalogues.

While many apps are not validated, they can be empowering to those at the workface. Two validated apps that are likely to have longevity are:

- NIOSH Sound Level Meter app—backed up by quality NIOSH research, available for iPhone
- the Predicted Heat Strain Mobile app—developed by the University of Queensland, available for iPhone.

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Postscript

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