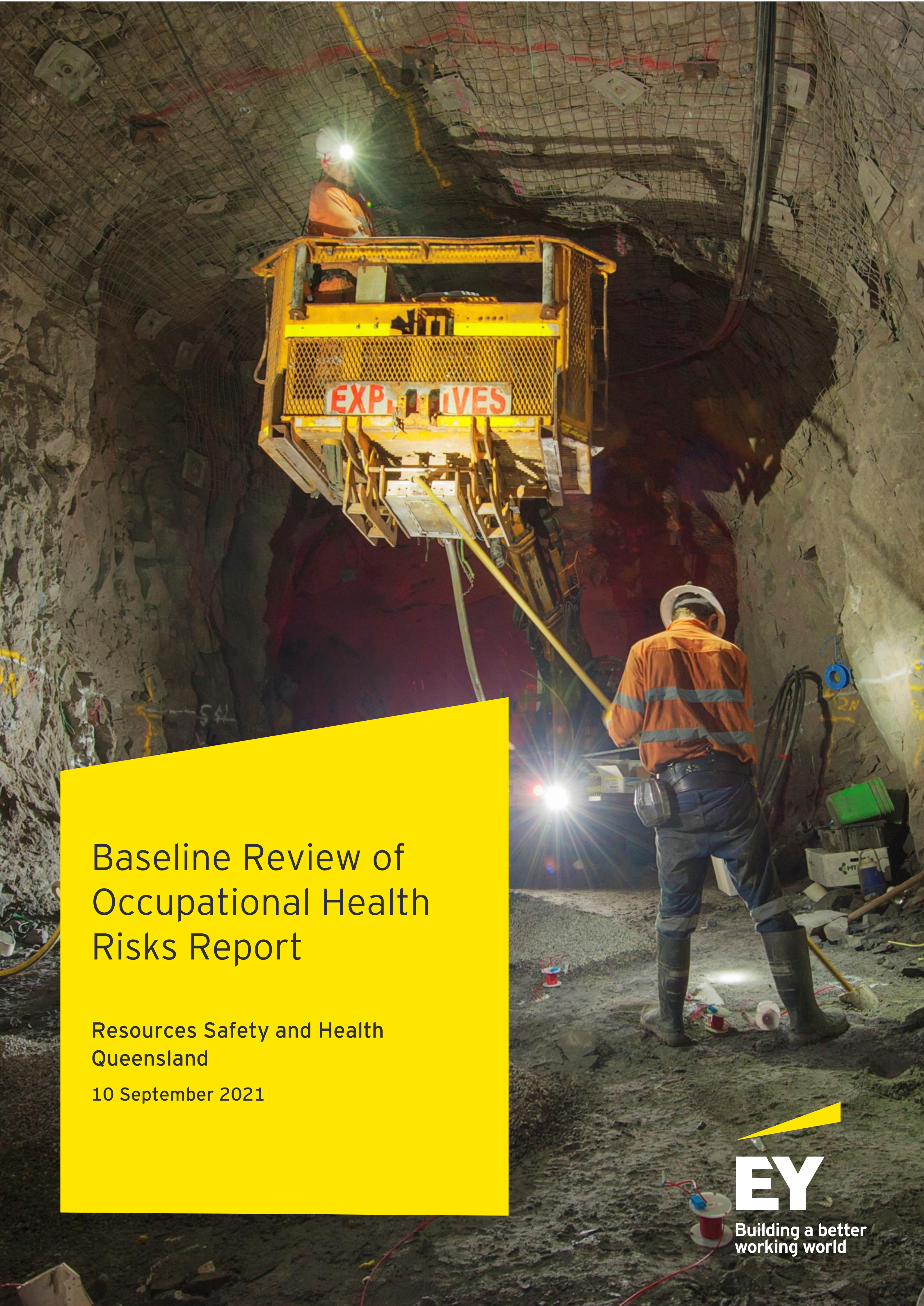

Baseline Review of Occupational Health Risks Report

Resources Safety and Health Queensland

10 September 2021

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Building a better working world

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Executive summary

1. Preface

The baseline review conducted by the research team for this report explored a number of key concepts relating to occupational health, occupational hygiene, statistical analysis, and epidemiology. For brevity, the research team has not provided all relevant background information on these key concepts in this review-findings report.

Interested readers, as well as those newer to the fields of occupational health and hygiene, may wish to explore the Occupational Health and Safety Body of Knowledge (BoK) before reviewing this report in depth.

The OHS Body of Knowledge (OHS BoK) is the collective knowledge that should be shared by generalist OHS professionals to provide a sound basis for understanding the causation and control of work-related fatality, injury, disease and ill health (FIDI). This knowledge can be described in terms of its key concepts and language, its core theories and related empirical evidence, and the application of these to facilitate a safe and healthy workplace.

The Body of Knowledge is available at www.ohsbok.org.au. The OHS BoK chapters that have been referenced in this report, as well as those not referenced but pertaining to the risks explored here, provide useful background reading for those less acquainted with the subject matter.

The research team extends its thanks to the Australian Institute of Health and Safety, and those authors who generously provided their time and expertise to develop this invaluable resource.

2. Executive summary

2.1 Overview

The EY and UQ team ('the research team') was engaged by Resources Safety and Health Queensland (RSHQ) to conduct a baseline review of occupational health risk data relevant to the resources sector in Queensland. This included RSHQ supplied data, information from other regulators and government departments, peer reviewed literature, interviews with RSHQ staff members, and other relevant data sources. This review is intended to inform the priorities and strategies for the regulation and surveillance of occupational health risks within the sector.

It is important to note that the baseline review was not an occupational health risk assessment. This report provides an outline of the review findings of the current state of knowledge on each health risk, the data available and gaps that exist, and the current approach to regulating and providing guidance on each health risk discussed in this report. It is also intended to focus on the information most pertinent to the Queensland resources sector and is not a comprehensive systematic review of each risk.

All the health risks identified in this review are significant and important to measure, monitor, and further control. The order of the chapters in this report is alphabetical so as not to suggest that any particular risk is more important than another. We recommend RSHQ expand the focus of its health surveillance remit to encompass all the risks identified in this review. 'Surveillance' in this case includes reviewing any accessible monitoring data, tracking trends in data in government-run health assessment schemes, and to continue its hygiene monitoring activities of conducting targeted health risk assessments, and reviewing the effectiveness of health risk controls as part of mine entry inspections.

To make this work as effective as possible, there is a requirement for systems and processes to collect these data sets, where there presently is not any available. The research team is aware of plans to update data collection and management systems (including the replacement of Lotus Notes, and the introduction of the new ResHealth system). This review highlights the importance of thorough requirements gathering, taxonomy design, and a sound data collection and usage strategy, to ensure the success of any new digital system.

Psychosocial health risk is one area for which minimal data currently exists (e.g. the increased risk of developing a mental health diagnosis and/or committing suicide). This is a priority action area for Safe Work Australia, is a focus of Workplace Health and Safety Queensland, and has been the subject of several reports and publications produced by Australian resources sector regulators. There was minimal evidence reviewed which suggests that this area has been a focus for RSHQ in the past, however the risk is recognised to contribute significantly to chronic worker ill health. Collecting data to better inform the extent of this risk, and the effectiveness of controls in place to manage the risk, is highly recommended.

The availability of data within RSHQ for the remaining risks in this review varied, as did the quality of data that was available. Data was predominantly available in relation to monitoring dust, noise, lead, diesel particulate matter, high potential incidents, and lost time injuries. There was little to no accessible quantitative hazard assessment data available in relation to psychosocial health, cardiovascular health, musculoskeletal disease prevention, and vibration.

While noting jurisdictional overlaps with mining and workplace health and safety legislation, very little health monitoring or risk surveillance data was available for the petroleum and gas, and explosives sectors. This was also the case when seeking data relevant to these sectors from outside of RSHQ. Targeted risk assessments may provide a greater impact on prioritisation initiatives in these sectors, compared with coal mining, and mineral mines and quarries, where there was generally more data available.

RSHQ has two options available to address the shortage of internal data that informs the state of these risks:

a. Use the data sourced from other jurisdictions and peer reviewed evidence, as included in this baseline review, to inform the severity and extent of exposure to each risk, and use it for prioritisation of risks, and/or

b. Conduct targeted health assessments which encapsulate collection of data, for those risks where little to no data exists, and use this data to assist in prioritising health risk management initiatives within RSHQ

While the impacts of exposure to health risks are not always felt immediately by the resources sector, and Queensland society at large, chronic illnesses borne by exposure to these risks are significant, both in terms of cost to society and the quality of life of those affected by these illnesses. The latency of these impacts adds another layer of challenge to building a sense of urgency for better identifying and mitigating these risks. The work that RSHQ does today, to mitigate the impact of exposure to these risks in the future, will be important and significant.

The research team are not aware of any similar initiatives to review occupational health risk being undertaken by any other resources regulators, whether in Australia or overseas. We recognise this forward-thinking approach and welcome the opportunity to assist RSHQ in establishing itself as a thought leader in health risk management from a regulator's standpoint.

2.2 Method

RSHQ provided information and data to the research team, including:

- Selected health risk assessments
- Approved data collection forms used for the Coal Mine Workers' Health scheme
- Suggested medical examination and report forms for mineral mines and quarries respiratory health surveillance
- Personal air sampling results for dust and diesel particulates
- Blood lead sampling data
- Selected mine entry reports
- Lost Time Injury (LTI) and High Potential Incident (HPI) data from 2011 - 2020, and
- Workers' compensation (WC) data.

The research team was also provided with copies of the relevant Acts and Regulations, Inspectorate Directives, Recognised Standards, Guidelines, and Guidance Notes. Some materials produced by Workplace Health and Safety Queensland and Safe Work Australia were also provided as they were identified as relevant by the RSHQ project team.

Information from other regulators and government departments, peer reviewed literature, and other relevant data sources and reports identified by the research team were also included. Every chapter in this report has a list of references, showing what was included in the review.

The team was tasked with reviewing the following known occupational health risks:

- Mental health and suicide
- Musculoskeletal disease (MSDs)
- Cardiovascular risk
- Whole body vibration
- Hand arm vibration
- Noise
- Dust and diesel
- Welding fume and metal dusts
- Blast fume
- Asbestos
- Lead
- Ionising radiation
- Non-Ionising radiation
- Polymeric chemicals
- Volatile organic compounds
- Other hazardous substances

Given this extremely broad scope, risks such as fatigue, heat stress, and viruses that are predominantly a safety matter, or where health effects were likely to be more acute than chronic, were excluded from this review. They are mentioned in reviews where cumulative exposures, or exposures combined with exposure to other health risks, could have a chronic impact, but were not reviewed as distinct health risks.

The research team was also asked to identify and review up to five emerging health risks, of which the following were identified and assessed:

- Engineered nanoparticles. This was identified through the review of publications from the Department of Mines and Petroleum in Western Australia, and peer reviewed evidence identifying this hazard.
- Psychosocial risks of reduced job security, not only due to market impacts, casualisation, automation etc, but also due to climate change mitigation policies and severe weather events. This was identified through work previously conducted by members of the research team. For the purposes of this baseline review, the discussion of these risk factors has been consolidated into the overall discussion on work related psychosocial risk exposure.

- Factors such as the changing nature of resources work, including itinerant work, automation, increasingly sedentary work, and access to occupational health expertise, were identified as impacting a number of the risks discussed in this review. These risks were identified through the industry experience of the research team and supported by evidence available on the topic. These factors have been discussed as relevant to the risks identified in this baseline review.

- Welding fumes as a carcinogen, in addition to the more known and understood effects of metal fume fever and heavy metal poisoning. This was identified through literature published by bodies such as the American Council of Governmental Industrial Hygienists (ACGIH) and the US National Institute of Occupational Safety and Health (NIOSH).

For each identified risk factor, available RSHQ data was reviewed, any relevant additional literature or data was identified and reviewed, and this was then assessed against any available risk assessment and/or exposure assessment methodologies, to provide insights into the extent of risk exposure within the Queensland resources sector workforce.

The research team performed an evaluation of regulation of each risk in Queensland and compared the regulatory approach in Queensland with the approach taken by other resources regulators in other Australian states. In some cases, where relevant, the regulatory analysis extended to regulators who have regulated a risk more extensively than other jurisdictions, or taken a markedly different approach, e.g. the approach taken by Comcare to the management of psychosocial risk.

2.3 Legislation applicable to the resources sector in Queensland – an overview

The research team were requested to evaluate what legislation currently applies to the identification, assessment, and control of each health risk identified in this report. Specifics are provided for each health risk in their respective chapter, where obligations on employers have been explicitly legislated. In some instances, however, legislation does not mandate specifics in respect to the management of a given risk. In these cases, the duty of employers to provide a workplace free from hazards and risks, to an extent as far as is reasonably practicable, would apply.

These general duties are outlined in the following Acts and Regulations:

a. Division 1 of the *Mining and Quarrying Safety and Health Act (1999)* requires operators to identify, assess, and control safety and health risks to 'as low as is reasonably achievable'. This is outlined further in Chapter 2 of the *Mining and Quarrying Safety and Health Regulation (2017)* which provides specifics on the application of the risk management process.

b. The *Coal Mining Safety and Health Act (1999)*, part 2, requires coal mine operators to identify, assess, and control safety and health risks 'to ensure the risk to coal mine workers while at the operator's mine is at an acceptable level'. The *Coal Mining Safety and Health Regulation (2017)* requires coal mine operators to implement a safety and health management system based on a risk management framework.

c. As outlined in the departmental Memorandum of Understanding between RSHQ and Workplace Health and Safety Queensland [1], workplaces which are not subject to comply with either sets of legislation in a) or b) above are required to comply with the *Work Health and Safety Act (2011)* and the *Work Health and Safety Regulation (2011)* which both impose a general duty on employers to provide a system of work which minimises risk to a level as low as is reasonably practicable.

2.4 Findings

Much of the quantitative data available from RSHQ focused on physically quantifiable risks such as noise, dust, fumes, and diesel particulate matter. Those less quantifiable risks, such as mental health and suicide, cardiovascular health, musculoskeletal disease, and vibration, had little to no RSHQ-provided data associated with their evaluation. Where available, data was sourced from other Australian agencies and/or peer reviewed literature to assist in quantifying the risks. This also enabled comparison of risks within the scope of this review, given the effort that would be involved in collecting, analysing, and synthesising any relevant and/or available RSHQ data to aid in the evaluation of risks.

The research team have all participated in projects involving operators in the resources sector in Queensland. Through this experience, the team have an understanding of the health risk data typically collected by industry operators. Obtaining access to this data in a deidentified format would assist RSHQ in better understanding the current state of risk management of most of the risks to which RSHQ currently have limited visibility.

In some instances, qualitative data was provided, but was lacking some important details to provide a meaningful analysis. These gaps included:

- Respirable dust, silica dust, and diesel particulate matter (DPM) had a reasonable amount of data available to aid in the analysis of these hazards for coal mining and in the mineral mines and quarries (MMQ) sectors. Some issues were identified with the design and use of similar exposure groups (SEGs) when analysing dust data for MMQ, and was excluded from the analysis. Dust and diesel particulate data was not provided for petroleum and gas, or the explosives sector. It should be noted that the research team would not anticipate as extensive an exposure to these risks within the petroleum and gas or explosives sectors.

- Health risk assessments contained a summary of data relating to noise risk assessments, however the raw data from noise sampling and audiometric assessments was not available.

- For sampling data for isocyanate, phenol, and blood lead data, Similar Exposure Group (SEG) data was needed (but missing) to enable a comparison of occupations and workgroups, to determine where and when higher risk exposures may be occurring.

- Blood lead results did not include SEG data or an indication of reproductive capacity.

- For lagging indicator data, mechanism of injury data and occupation data was typically insufficient to allow an analysis of trends in task or SEG that would sufficiently quantify the risk. Having data including occupation, and task performed when the injury occurred, would allow for a more targeted analysis of the risk factors that gave rise to the injury (e.g. musculoskeletal disease or a condition associated with exposure to vibration).

These are examples, and gaps in the data relevant to each risk are explored in the discussion of each individual risk.

Challenges are presented when attempting to review risks in isolation, without considering the synergistic effect of cumulative health risk exposure. Health monitoring is further complicated by the increasingly itinerant nature of the mining workforce and the use of contractors and subcontractors who work across many industries. Consequently, the workers' compensation (WC) data associated with resources sector health risk exposures may be assigned to other industry sectors. Accuracy of WC data is reliant on the individual being assessed, upon the disease being associated with work, and the claim being made to the appropriate industry. Past investigations have demonstrated the potential inaccuracies of relying solely on WC data to estimate the occupational disease burden on the Queensland mining industry.

In these cases, it may be more productive to focus on leading indicators, such as noise level monitoring for noise risk tasks, rather than hearing loss claims or changes in audiometric testing results. The longer the lag between exposure to a risk, and the development of symptoms of disease, the more critical the collection of leading indicator data. This can identify an issue before it becomes a compensable disease. Worker medicals and fitness for duty assessments collect information that could be analysed and benchmarked against the general population to indicate trends.

The research team's understanding is that there is data available for analysis in various RSHQ databases, but the significant effort and expense required to extract, cleanse, analyse and trend the data outweighs the benefit that would be gained from such an undertaking. RSHQ is presently designing and implementing an improved system to collect and monitor worker health surveillance data that will help address this issue going forward.

This baseline review serves to highlight the importance of improving data collection systems, processes, classification taxonomies, reporting dashboards, and business processes to action the data and iteratively improve data collection and usage strategies. Taking a tripartite approach (i.e. RSHQ, industry, and unions/ employee representative bodies) to the development of these systems is likely to result in a more engaging and sustainable solution.

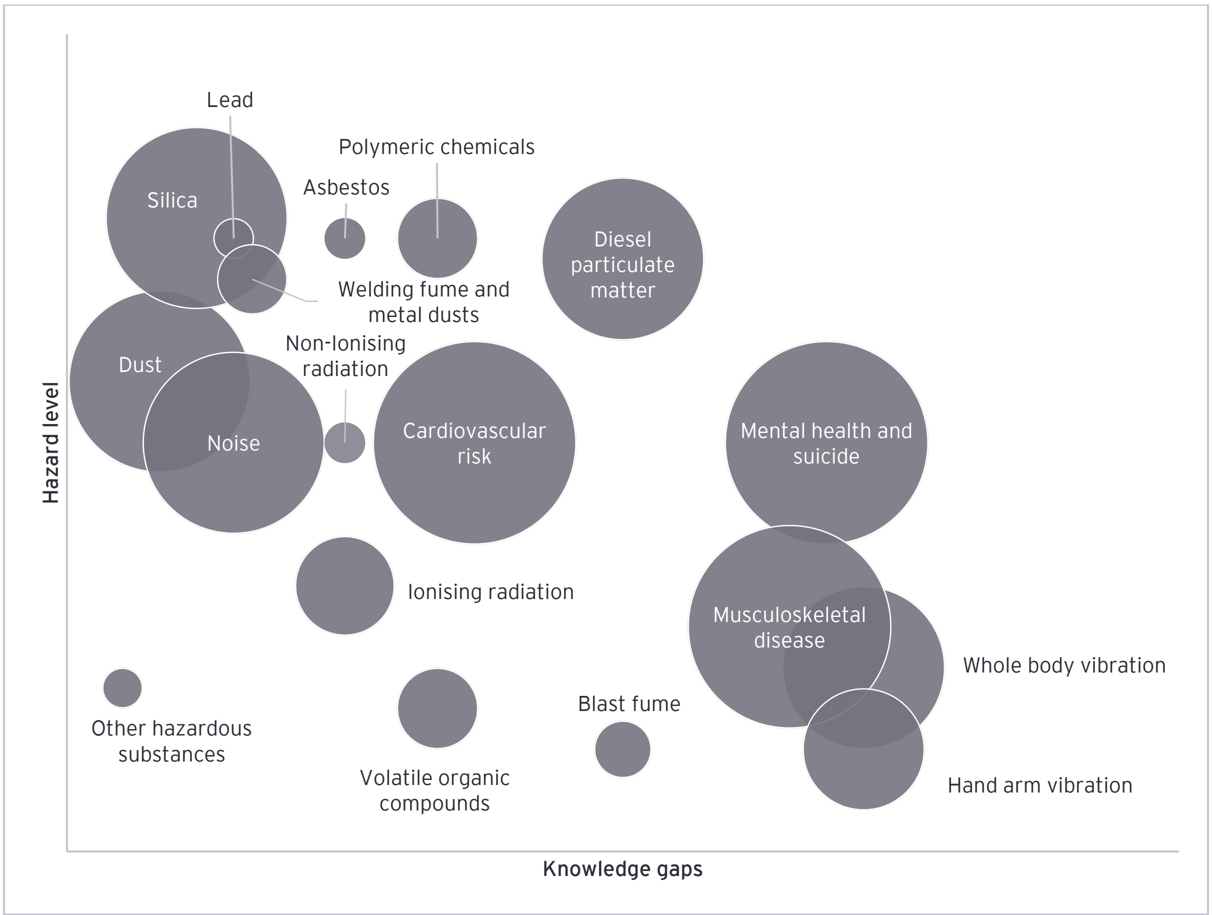
2.4.1 Evaluation of the current state of occupational health risks

The research team evaluated each of the health risk assessed and compared:

- The availability of knowledge on the health risk and associated effects, and the relationship/s between exposure and effect (both internally, and external to RSHQ)
- The known severity of health effects resulting from exposure to the hazard
- The probable frequency and duration of exposure to the hazard
- The probable size of the population exposed to the hazard, independent of the actual degree of exposure (which in most cases is not currently quantified)

Each of these factors was scored, for each health risk, on a scale of 1 to 5, where 1 was a 'minimal' rating for each parameter, and 5 was the maximum degree of severity, frequency/duration, and population size. Knowledge of the risk was rated where 1 was a high level of knowledge, and 5 was a very poor level of knowledge within RSHQ, based on available data. This data was used to generate the below 'bubble graphs', where the size of the bubble represents the size of the population exposed, multiplied by the extent of exposure to the risk.

2.4.2 Evaluation of the current state of occupational health risks across all Queensland resources sectors



2.4.2.1 Findings overall

The data validates RSHQ's current degree of focus on silica, dusts, and DPM, given these risks have some of the highest hazard severity ratings. Polymeric chemicals, asbestos, and lead were hazards with a severe rating and a relatively better degree of knowledge of the risks. Mental health and suicide, and cardiovascular risk, had a moderate degree of severity associated with them, and greater knowledge gaps. The greatest knowledge gaps existed in the areas of musculoskeletal disease, and vibration (both whole-body and hand-arm vibration).

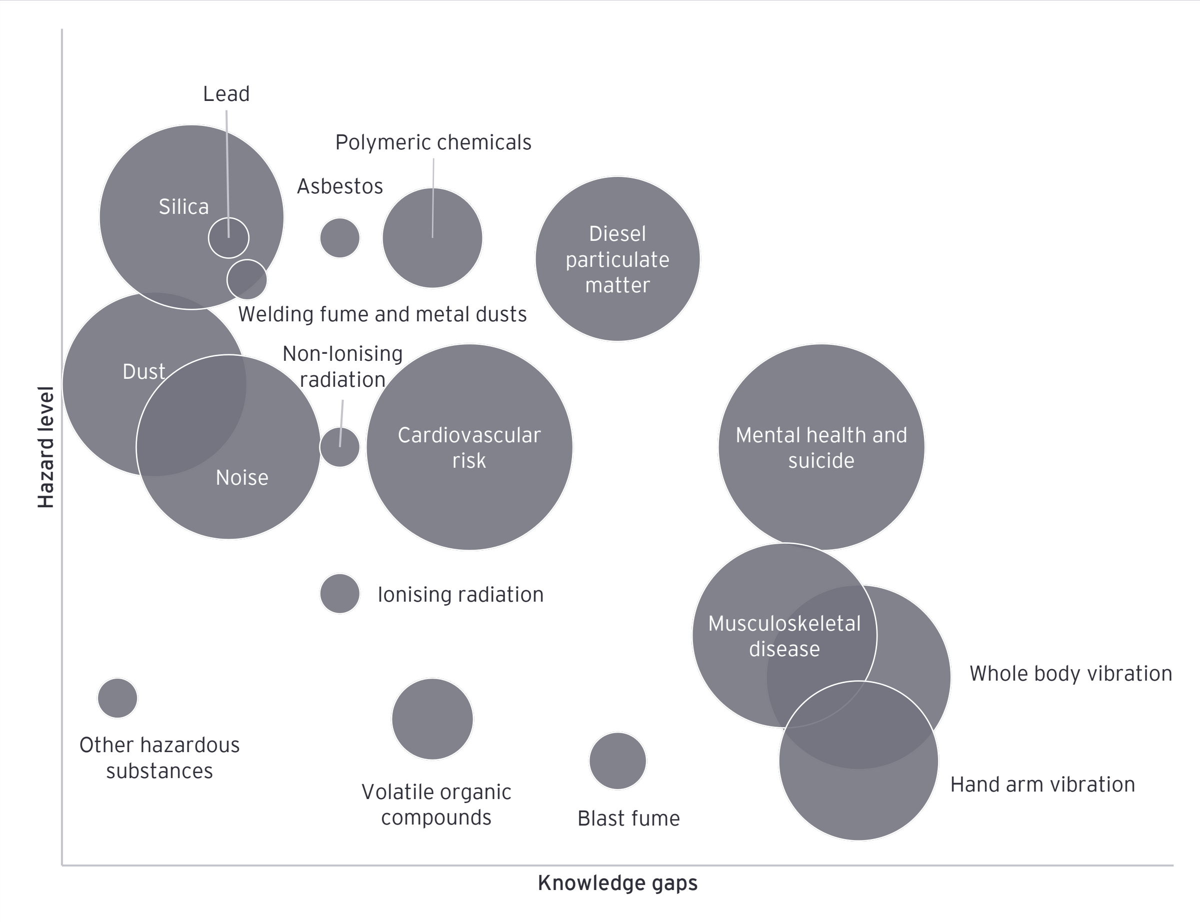
Interviews with a limited number of individual RSHQ staff, including inspectors and occupational hygienists, were focused in a manner commensurate with the volume of available data for each health risk. Staff were able to provide more background and information about the risks that had more data associated with them (e.g. dusts and fumes) than those risks with little associated data (e.g. mental health, vibration, or cardiovascular disease risk).

Staff working within inspectorates stated they had limited awareness of some validated semi-quantitative assessment tools that would aid surveillance of these risks (e.g. the Kessler Psychological Distress Scale for screening for increased risk of psychological injury, or the Occupational Cumulative Risk Assessment tool for musculoskeletal risk). This suggests there is an opportunity to provide education to RSHQ staff on the use of semi-quantitative assessment tools, particularly for those lesser understood risks of psychosocial health, musculoskeletal disease prevention, and vibration.

A comparison was conducted for each sector regulated by RSHQ, and the results of this exercise are as follows:

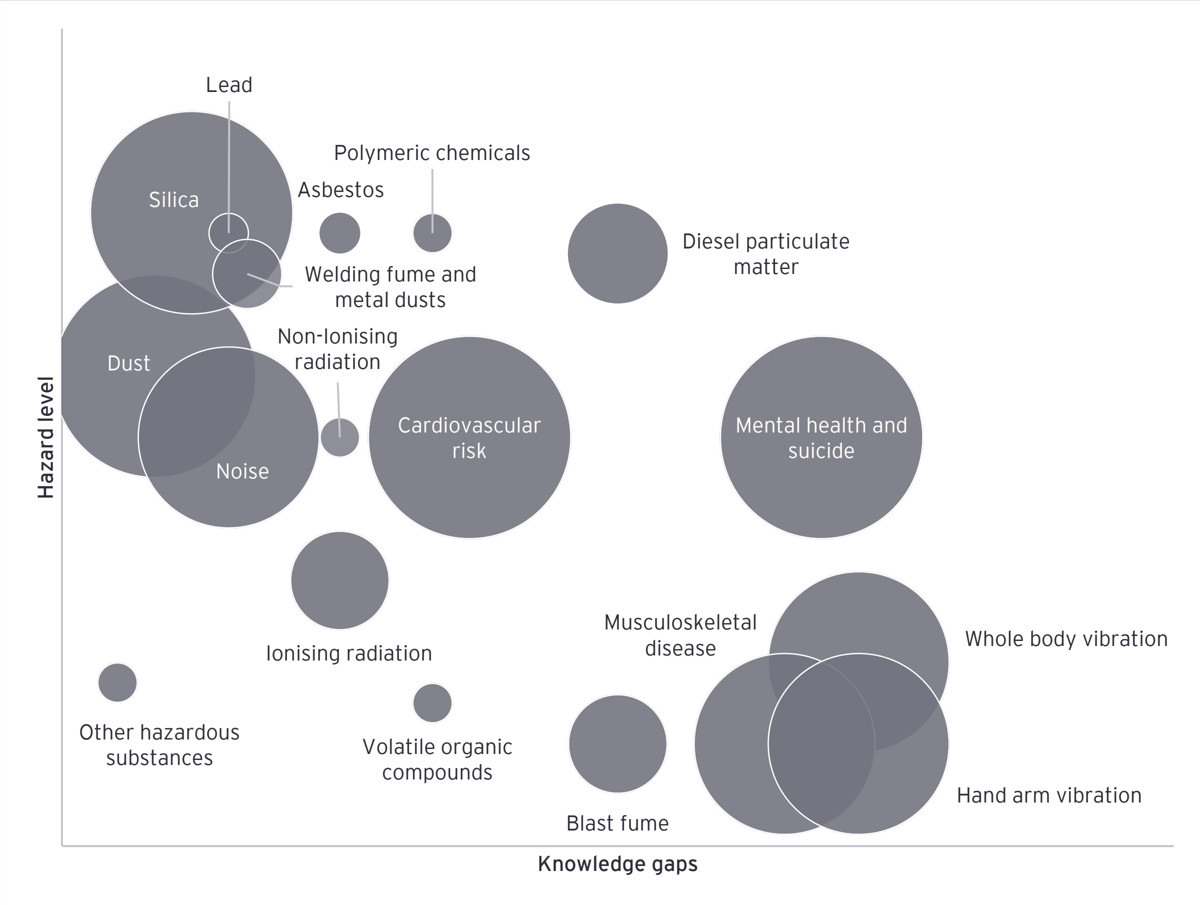
2.4.2.2 Evaluation of the current state of occupational health risks in the underground coal mining sector

Priorities in the underground coal sector are comparatively similar to our analysis of the resources sector overall:



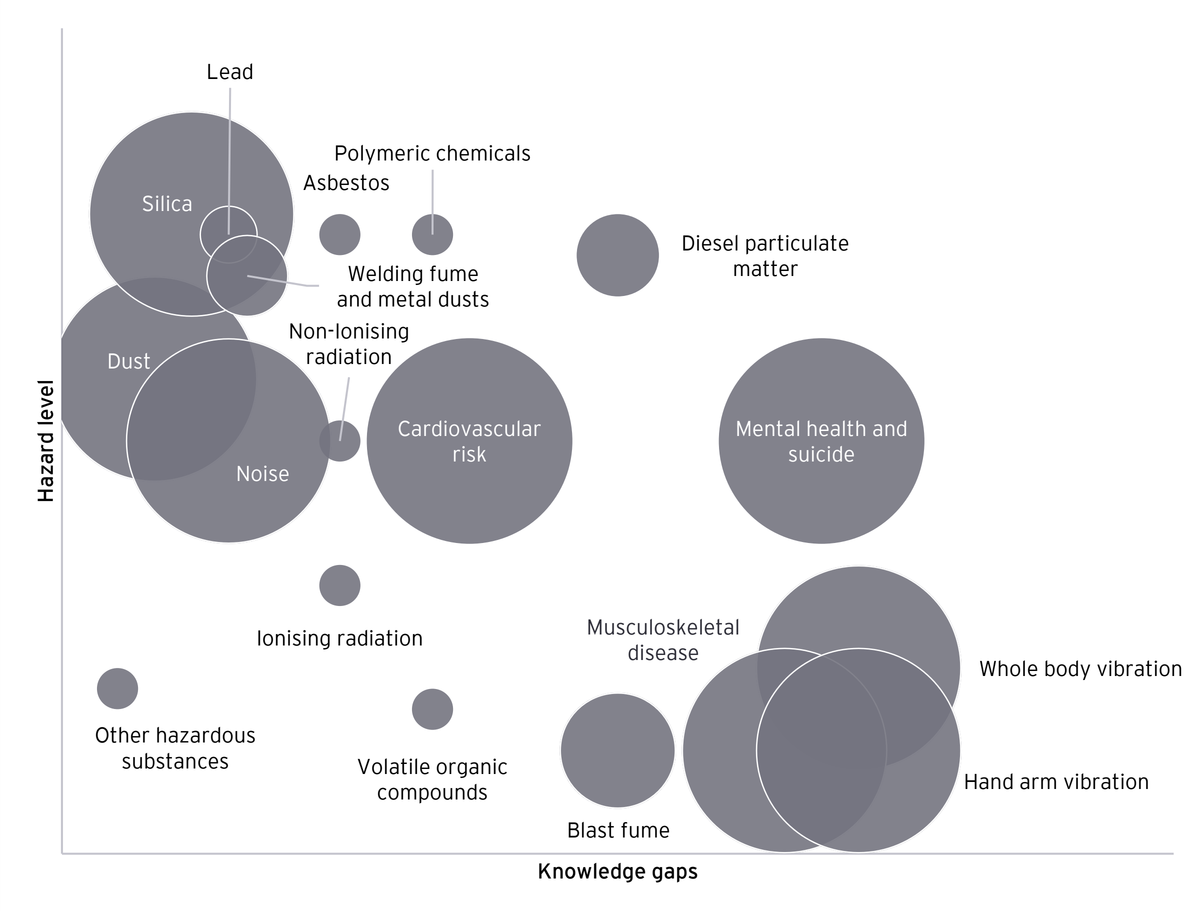
2.4.2.3 Evaluation of the current state of occupational health risks in the open cut coal sector

Population and exposure ratings were higher for blast fume, and ionising radiation. MSDs were considered to be less significant a hazard owing to the less demanding nature of manual tasks within the sector.



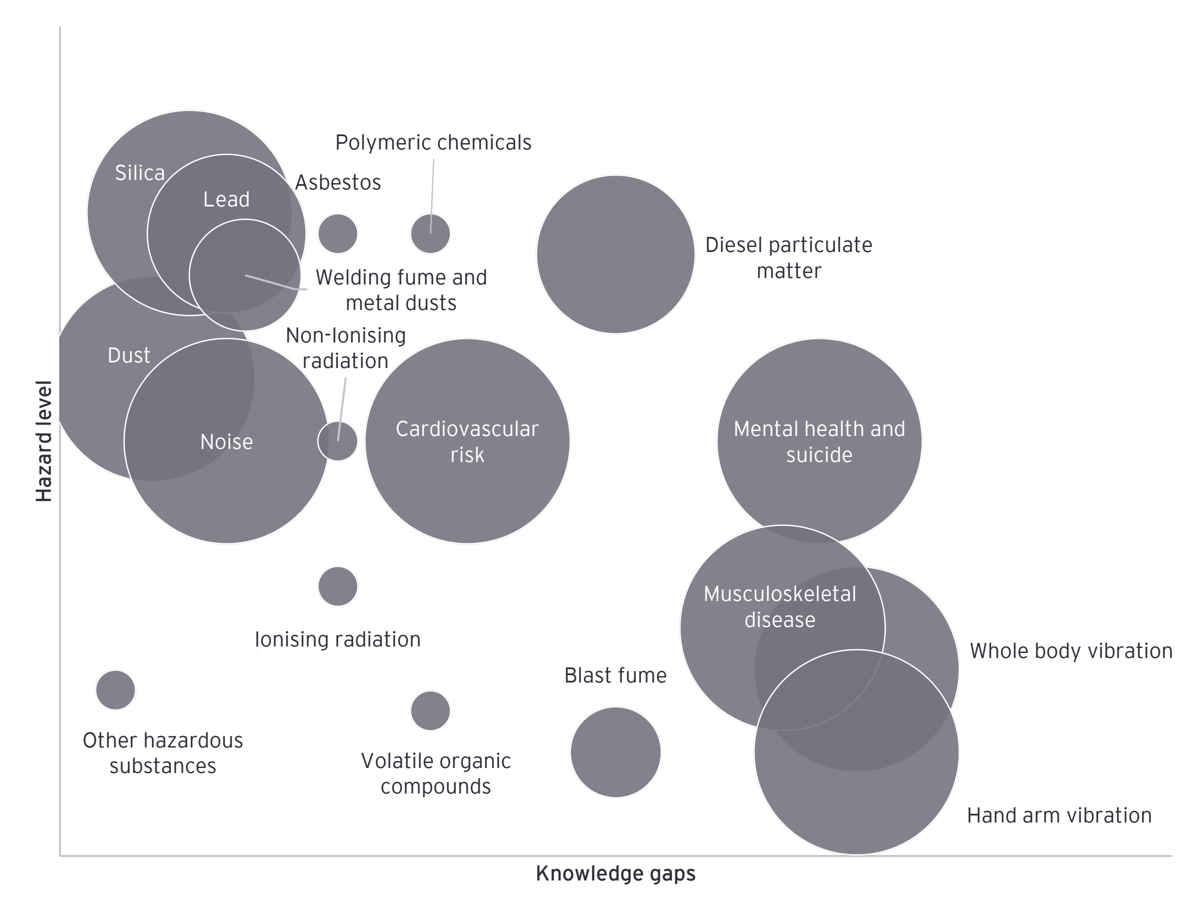
2.4.2.4 Evaluation of the current state of occupational health risks in the open cut metalliferous sector

A larger population is exposed to lead and metal fumes in this sector, compared to other sectors. Population and exposure ratings are higher for ionising radiation and blast fume.



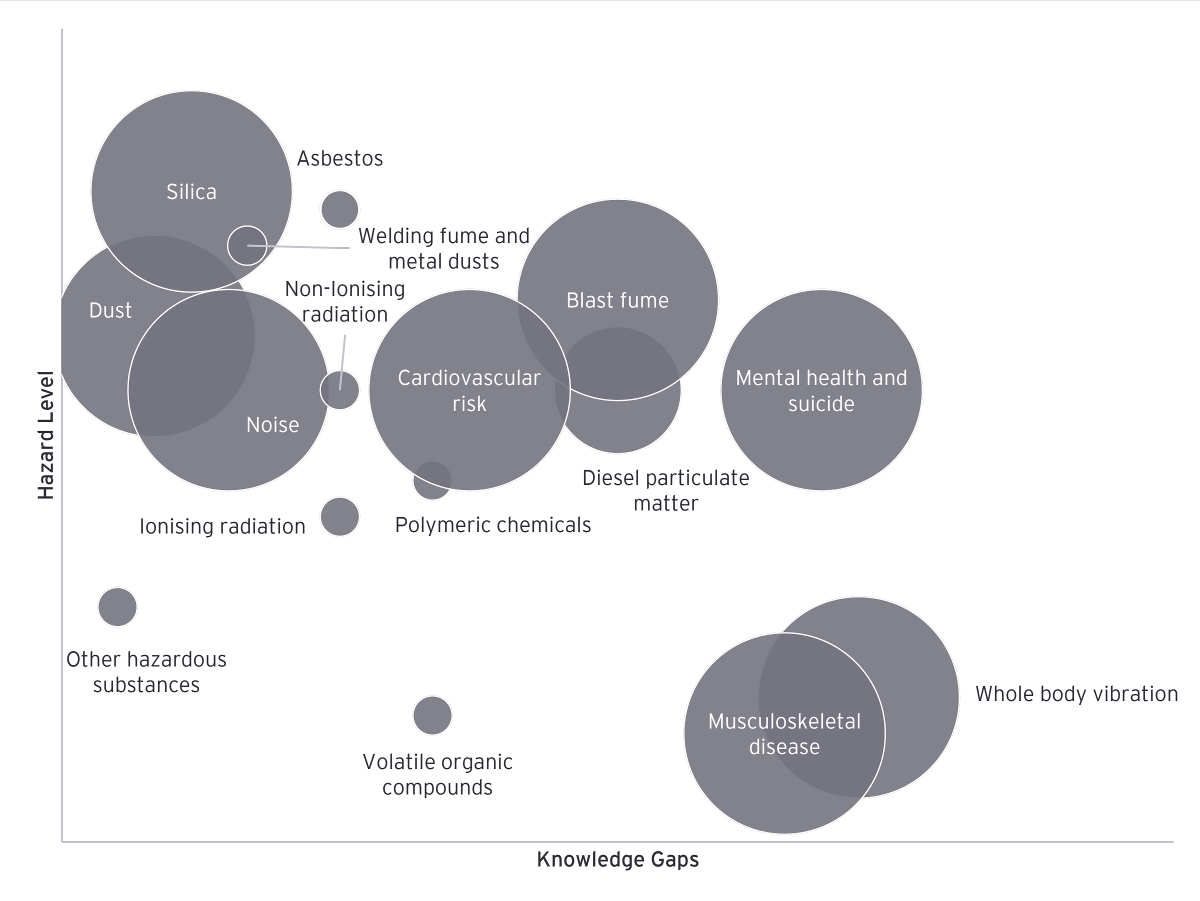
2.4.2.5 Evaluation of the current state of occupational health risks in the underground metalliferous mining sector

Welding fume and metal dusts were considered a greater hazard with a larger population exposed. Lead and blast fume exposures are greater in this sector.



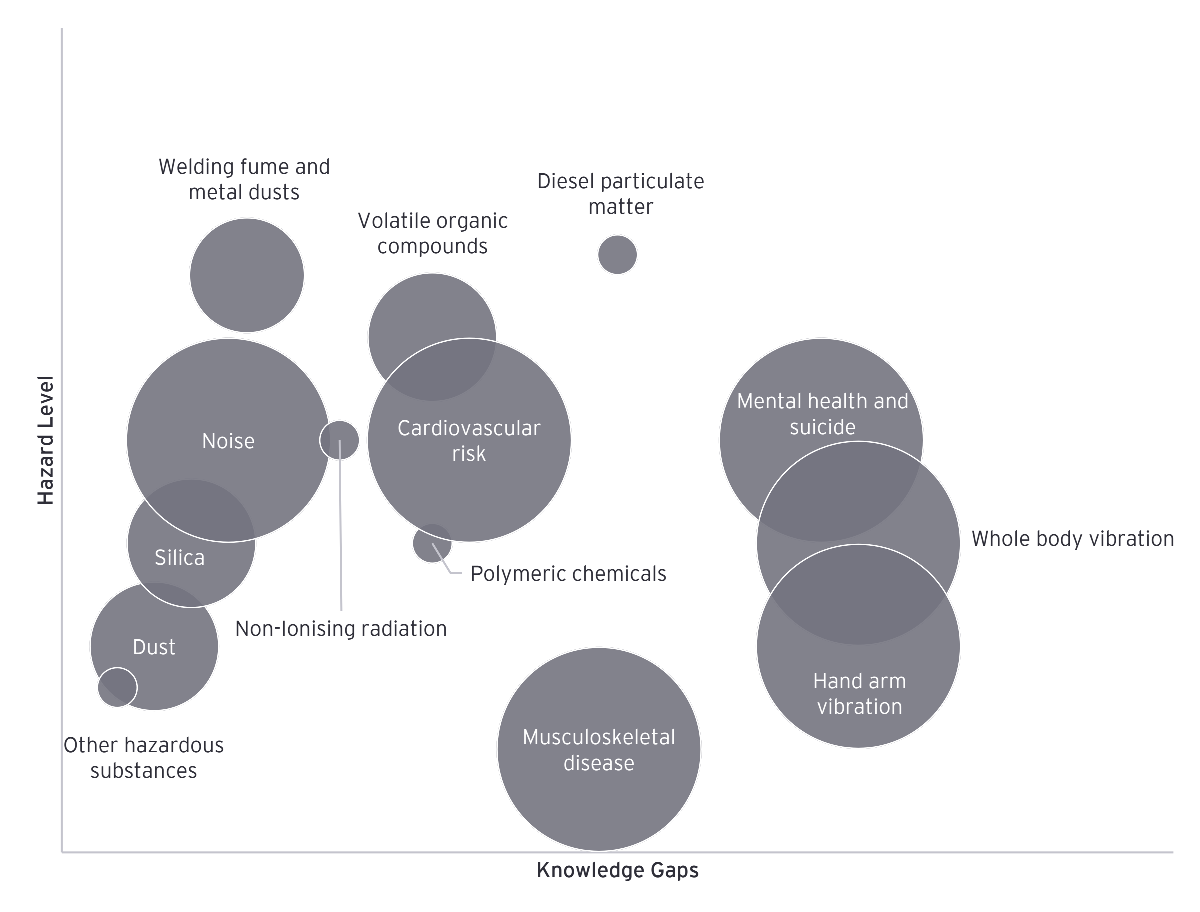
2.4.2.6 Evaluation of the current state of occupational health risks in the explosives sector

Blast fume exposures are considerably greater. MSDs and vibration are less of a hazard owing to the design of tasks in this sector requiring less manual labour and less use of equipment that generates vibration. Hand-arm vibration is not considered to be a hazard.



2.4.2.7 Evaluation of the current state of occupational health risks in the petroleum and gas sector

Dust, silica, and MSDs are less of a hazard. Exposure to DPM is less prevalent.



2.5 Discussion

The availability of internally collected data was limited outside of dust, DPM, and lead. None of the risks assessed were identified as having a likelihood of zero harm to resources sector workers, whether in Queensland or a similar jurisdiction.

The research team have used the data available from RSHQ, and data available from other jurisdictions, peer reviewed literature, and reports from credible sources, to evaluate the risks explored in this report. Our review suggests that dust, silica, lead, and DPM present a significant hazard to workers exposed to these risks, and should remain a focus for RSHQ. Knowledge gaps exist for some risks with significant health effects, particularly mental health and suicide, and consideration should be given to better understand the state of these risks to assist with prioritising hygiene monitoring and health surveillance.

In collecting further data and prioritising future risk focus, it is important to note the interrelatedness of these risk factors when determining the overall impact on worker health in the Queensland resources sector. Many of the risks identified have amplifying or cumulative effects on total worker health (e.g. increased psychosocial risk amplifies symptoms of musculoskeletal disease, and vice versa), and subsequently the entire health risk picture needs to be considered when making decisions on how to prioritise the management of individual risks.

The identification of the increasingly itinerant nature of the workforce presents its own challenges for longitudinal surveillance of worker health. Where previously, workers would have participated in ongoing hygiene monitoring and health surveillance over their career, they may now complete a short stint in the resources sector, and then leave the sector for work elsewhere. This presents a challenge for RSHQ in identifying the health impacts from the time these workers were employed in the resources sector and attributing those health effects to the resources sector work they did, separately to work performed in other sectors.

Currently the management of occupational health is scattered throughout the resources sector legislation, with sections dealing with fitness for duty, exposure to hazardous substances, dust, noise, blast fume (in the explosives act), medical assessment requirements, etc. As such, the management of occupational health is fragmented. An approach could be taken like the one adopted by the Resource Regulator in NSW, where a health control plan is required. This would draw all the elements of occupational health risk management under one management framework and allow for easier coordination of actions required for effective, integrated occupational health risk management activities. This concept is not dissimilar to the current requirement under coal mining safety legislation in Queensland to develop and implement a safety management plan.

These health control plans are informed by occupational health risk assessments and are similar to a site safety management plan, but with an occupational health focus. In NSW, these are reviewed by inspectors as part of an entry visit, much as safety management plans are reviewed by RSHQ inspectors at present.

Another initiative in NSW is the use of targeted assessment programs where inspectors conduct an in-depth review of one key health risk at a subset of sites to gauge the significance of the issue. This obviates the need for blanket data collection, improves data collection effectiveness, and the depth of the data collected. The approach has provided greater visibility to those targeted health risks, has served to better inform the health strategy for the regulator, and ensured a data-driven approach is taken to managing the balance of focus between acute fatality prevention, and the management of risk factors that contribute to the development of chronic disease.

2.6 Conclusion

The research team has endeavoured to capture the current state of health risk management for identified and emerging health risks in the resources sector in Queensland. Fully quantifying and evaluating each risk was made more challenging by the shortage of quality, quantified health risk data available, specific to the resources sector in Queensland. (This includes monitoring, surveillance, and claims data).

Specific physical risks such as dust and fumes had more data available and were generally better understood by RSHQ. This is valid considering the degree of hazard presented by these risks, and the size of the population exposed to them. Risks such as vibration, chemical hazards such as volatile organic compounds (VOCs), musculoskeletal disease risk factors, and psychosocial risk factors had very little data associated with them and were generally less well understood.

The research team recommends that RSHQ continues to focus on improving the quality and quantity of data for risks where data collection is already occurring, such as dusts, fumes, and noise. RSHQ should also extend their efforts to collecting data for those risks where there is very little data at present, particularly psychosocial risks, musculoskeletal disease, vibration, and cardiovascular risk, since these risks are well known contributors to chronic worker ill health. Once these risks are better understood, it will be easier to include identified emerging risks in RSHQ's health surveillance and hygiene monitoring activities.

Options available to better inform the current state of these risks include reviewing data from outside Queensland, as discussed in this report, and extrapolating this data to the Queensland context, as well as conducting targeted risk assessments on those hazards where less data is available.

RSHQ are to be commended for further interrogating the state of health risk management in the resources sector in Queensland. The steps taken to better manage health risk, taken based on this baseline review, will benefit the health of thousands of Queensland resources sector workers, their families and friends, for decades after this action occurs.

1. Workplace Health and Safety Queensland, *Memorandum of Understanding between Office of Industrial Relations and Resources Safety and Health Queensland*. 2017.

2.7 Research team

The researchers who conducted the baseline review and compiled this report are a multi-disciplinary team with expertise in various fields relating to occupational health and safety in the resources sector.

Professor David Cliff

David Cliff is Professor of Risk and Knowledge Transfer, Minerals Industry Safety and Health Centre, University of Queensland.

- David has been undertaking research, consulting, and providing education and training to the Mining Industry in Australia and overseas for over thirty years. He has published over a hundred articles on OHS in Mining and managed more than twenty research projects.
- He has extensive experience across a broad spectrum of OHS issues including fires and explosions, fatigue management, occupational health, occupational safety, OHS management systems, Risk Management, key performance indicators for OHS, leading, lagging, and positive. He has been an expert witness in several major mine disasters as well as the recent inquiry into the resurgence of black lung.

Dr Kelly Johnstone

Kelly Johnstone is a Senior Lecturer in the Faculty of Science at the University of Queensland.

- Kelly is both an occupational hygienist and occupational health and safety (OHS) generalist with a focus on the protection of worker health. She is a Senior Lecturer in the School of Earth and Environmental Sciences, within the Faculty of Science at the University of Queensland. Kelly has experience in a range of industries, including education, the energy and resource sectors, construction, transport, and agriculture. She plays an active role within both the Australian Institute of Health and Safety (AIHS) and the Australian Institute of Occupational Hygienists (AIOH).
- Her PhD research investigated the use of a new biological monitoring tool for the assessment and management of Australian farmer's exposure to organophosphate pesticides. She has previously worked on applied and academic projects in indoor air quality, exposure to waste anaesthetic gases in animal research, thermal risk assessment, and a range of OHS management related projects.

Dr Danellie Lynas

Danellie is Senior Research Fellow, Minerals Industry Safety and Health Centre, Sustainable Minerals Institute, University of Queensland.

- Danellie's areas of expertise focus on the identification of human factors and health related indicators that impact on worker safety from a risk management perspective, and the subsequent development and implementation of proactive interventions strategies.
- Danellie has been involved in research projects relating to the uptake of automation in the mining sector, occupational hygiene and occupational ergonomics, interface design for haul truck proximity detection systems and the validation and application of the whole-body vibration iOS application (WBV) for workplace management of whole-body vibration exposures.
- She has worked across several large-scale mining projects (both domestic and overseas), and as a consultant in health and safety in a number of non-mining industry sectors.

Nikky LaBranche

Nikky is an Industry Fellow in the Sustainable Minerals Institute at the University of Queensland.

- Nikky is Research Manager Occupational Health & Safety and was the inaugural Industry Fellow in the Minerals Industry Safety and Health Centre (MISHC) within the Sustainable Minerals Institute (SMI) at the University of Queensland. She specialises in mining occupational health and safety research with a focus on particulates.
- Nikky is currently undertaking a strategic gap analysis in the understanding and management of particulates in the resources sector. She is also pursuing her PhD characterising the impact of dust on the respiratory health of coal mine workers, for which she has been awarded the AusIMM Education Endowment Fund Postgraduate Scholarship.
- She is a mining engineer with 15 years' experience in surface and underground coal through her work in the US, Colombia and Australia. She is past chair of the AusIMM Southern Queensland Branch and has been awarded the John T. Boyd Young Engineers Award. Nikky has worked in various mining engineering roles for Simtars, BHP, and the NIOSH Office of Mine Safety and Health Research.

Andrew Toyer

Andrew is a psychologist (provisional), AHPRA, and Senior Consultant Climate Change and Sustainability Services.

- Andrew has a Master of Science–Work and Organisational Psychology, Maastricht University, and a Bachelor of Arts (Hons–Psychology), Macquarie University. He has been involved in several projects that cross over both mental health and research and has been involved in implementing program changes within organisations. He is currently completing another master's degree, specifically in Organisational Psychology at the University of Macquarie.
- He is an experienced researcher, program evaluator, analyst, and writer. He specialises in research, insights generation, stakeholder engagement and program evaluation, with experience delivering complex projects across the public and private sector.
- Andrew has contributed to the design and delivery of culture change programs and learning content for workforce and leadership groups within high-risk industry, delivered both online and face to face. He has worked with clients to build a shared safety culture and ultimately improve health, safety, environment, and quality (HSEQ) performance.

Elise Condie

Elise is a Senior Program Manager in EY's Health, Safety and Environment Services practice based in Brisbane.

- She is an AHPRA registered Physiotherapist, a Board-Certified Ergonomist and Human Factors Professional, holds a Masters in Ergonomics, and is a Sessional Lecturer for the School of OHS at RMIT.
- Elise has over 15 years' experience in safety and operational excellence, health & safety management consulting, including risk and strategy, governance, due diligence, culture and leadership, management system design and implementation, maturity/gap assessments, and internal audits.
- She possesses front line experience as an EHS professional in a diverse range of industries including underground mining, construction, utilities, healthcare, biotechnology, and pharmaceuticals.
- Elise's experience has been focused on designing and delivering safety and environmental performance improvement initiatives for large multinational corporations, with a focus on improving risk management, injury prevention, and building management and workforce capability for EHS management.

Dr Clare Wood

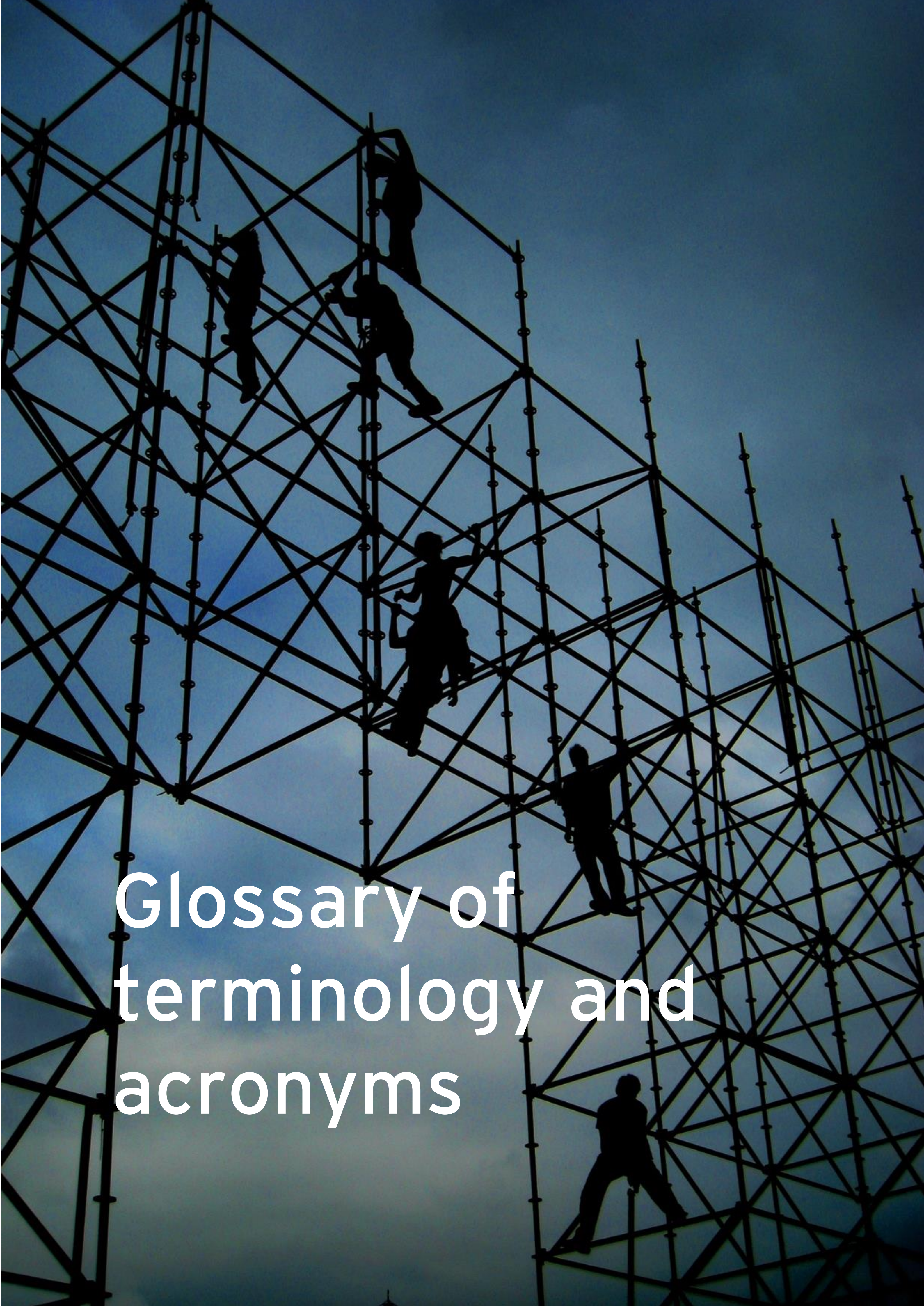
Dr Clare Wood is a Consultant Occupational and Environmental Physician (OEP) with more than five years' industry experience. She graduated from medicine in Birmingham, UK in 2004 and that year was awarded the Arthur Thompson Prize for Services to the Medical School. Prior to this, she gained her Bachelor of Science with Honours in Sports and Exercise Science at the same university.

Dr Wood moved to Australia in 2007, initially working at the Royal Brisbane Hospital as an Emergency Registrar with Queensland Health. It was during her work with Medibank Health Solutions that her interest in occupational health began and she went on to further her skills and knowledge by training to be a Fellow in Occupational Medicine.

In 2016, she was appointed to the position of Occupational Health Physician with the Department of Natural Mines and Resources in Queensland and her role included working on the implementation of the recommendations from the Monash Review to improve the respiratory health surveillance of coal mine workers. She is currently a consultant Occupational and Environmental Physician with OccPhyz Consulting, consulting across Queensland and Northern New South Wales.

Dr Wood holds a membership with AMROA as a MRO. She is a tutor with Griffith University in clinical skills to medical students. She is currently a member of the Human Research and Ethics Committee (HREC) for Ramsay Health Care. Dr Wood recently completed her SIRA NSW (MAA) course for providing independent medical examinations. She is currently undertaking further courses in permanent impairment to assist her in private practice.

Glossary of terminology and acronyms



3. Glossary of terminology and acronyms

This section defines health hazard terminology and acronyms used throughout this report.

AC	Alternating current
ACGIH	The American Conference of Governmental Industrial Hygienists
Aetiology	The cause, set of causes, or manner of causation of a disease or condition
AICIS	Australian Industrial Chemicals Introduction Scheme
AIHW	Australian Institute of Health and Welfare
AM/MVUE	Arithmetic Mean / Minimum Variance Unbiased Estimator—two different measures of the mean. AM is used for a normally distributed dataset and MVUE for a log normally distributed dataset.
ANRDR	Australian National Radiation Dose Register
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
AS/NZS IEC	Standards Australia and Standards New Zealand work together to develop joint standards, along with International Electrotechnical Commission, and other internationally recognized standards bodies.
BEI	Biological exposure index (established by the ACGIH)
BMGV	Biological Monitoring Guidance Value
BOEL	Biological Occupational Exposure Limit
CB	Control banding, a technique used to guide the assessment and management of workplace risks. It is a generic technique that determines a control measure (for example dilution ventilation, engineering controls, containment, etc.)
CMSHR	Coal Mining Safety and Health Regulation
CNF	Carbon nano-fibre
CNT	Carbon nanotube
CPC	Condensation particle counter
DEHP	Department of Environment and Heritage Protection (now known as Department of Environment and Science)
DMIRS	(Government of Western Australia) Department of Mines, Industry Regulation and Safety
DPM	Diesel particulate matter
EAV	Exposure Action Value (EAV) above which employers are required to control whole-body vibration risks, from the European Union directive 2002/44/EC (European Union Parliament, 2002). SafeWork Australia has published guidance information on vibration, but refers to the EU Directive
EC	Electrochemical
Effective Dose	In the context of ionising radiation, an effective dose is the amount of radiation that has an impact on the health of a person or organism.
ELF	Extremely low frequency (electric fields)
ELV	Exposure Limit Value (ELV) for whole-body vibration above which workers must not be exposed, from the European Union directive 2002/44/EC (European Union Parliament, 2002). SafeWork Australia has published guidance information on vibration, but refers to the EU Directive
EMF	Electric and magnetic fields
EMG	Electromyography refers to the recording of the electrical activity of muscle tissue, or its representation as a visual display or audible signal, using electrodes attached to the skin or inserted into the muscle
ENM	Engineered nanomaterials

EMR	Electromagnetic radiations (there is more than one type)
FA-HSA	Formaldehyde human serum albumin conjugate
FIFO	Fly In Fly Out
FMZ	Fume Management Zone
GC-MS	Gas Chromatography-Mass Spectroscopy
HAV	Hand-Arm Vibration
HAVS	Hand-Arm Vibration Syndrome – a neurological condition resulting from over-exposure to hand-arm vibration
HDI	Hexamethylene diisocyanate
Health Surveillance	Sometimes also referred to as Biological Monitoring—the practice of medical monitoring of workers who have exposures that have known or suspected health risks.
HIAC	Queensland Mining Health Improvement and Awareness Committee
HPI	High-potential incident
HSE	(UK Government) Health and Safety Executive
Hygiene Monitoring	The practice of tracking that a workplace is ensuring required safe practices to safeguard the health of workers.
IAEA	International Agency for Research on Cancer
IARC	International Classification of Diseases
ICD	International Classification of Diseases
ICNIRP	International Commission on Non-Ionizing Radiation Protection
ICRP	International Commission on Radiological Protection
IHD	Ischemic heart disease
Inbye	Pertaining to the direction towards the coal face
IPDI	Isophorone diisocyanate
IR	Ionising Radiation
IS	Isocyanate Symptoms
HGCZ	Health guidance caution zone
HPLC	High-performance liquid chromatography
LHD	Load, Haul, Dump machine
LTI	Lost Time Injury
MDG	Machine design guideline
MDI	Methylene diphenyl diisocyanate
MIC	Methyl isocyanate
MMQ	Mineral Mines and Quarries
MQSHR	Mining and Quarrying Safety and Health Regulation
MSD	Musculoskeletal Disease
NDI	Naphthalene diisocyanate
NEAT	Nanomaterial Exposure Assessment Technique (developed by NIOSH)
NIHL	Noise-Induced Hearing Loss
NIOSH	US federal agency: National Institute for Occupational Safety and Health
NHEWS	Australian National Hazard Exposure Worker Surveillance
NMAM	NIOSH Manual of Analytical Methods

NOHSC	National Occupational Health and Safety Commission (1985-2005)
NORM	Naturally Occurring Radioactive Material (such as uranium)
OCEs	Open-Cut Examiners or Open-Cut Environment
OCRA	Occupational Repetitive Actions (assessment tool)
OECD	Organisation for Economic Co-operation and Development
OEL	Occupational Exposure Limit, set by regulating authorities to protect the occupational safety and health of workers.
OPC	Optical particle counter
OSHA	US federal agency, Occupational Safety and Health Administration
Ototoxin	A substance that is toxic to the ear, and which causes hearing loss
Outbye	Going towards the pit shaft from the coal face (opposite of inbye)
PPE	Personal protective equipment
PAHs	Polycyclic Aromatic Hydrocarbons, such as Benz(a)pyrene
PCBs	Polychlorinated Biphenyls
PCBU	Person conducting a business or undertaking
PMF	Progressive Massive Fibrosis
Prill	A prill is a small aggregate or globule of a material, most often a dry sphere, formed from a melted liquid. Prilled is a term used in mining and manufacturing to refer to a product that has been pelletized. The pellets are a neater, simpler form for handling, with reduced dust.
PRU	The (UK) Pneumoconiosis Research Unit, established in 1945
PTS	Permanent Threshold Shift, permanent hearing loss as a result of acoustic trauma (exposure to noise)
PUR	Polyurethane
QGN	Queensland Guidance Note
RAZ	Restricted access zones
RCD	Respirable Coal Dust
RCS	Respirable Crystalline Silica
RF EME	Radio frequency electromagnetic energy
ROS	Reactive Oxygen Species
r.m.s.	Root mean square. The square root of the mean square (the arithmetic mean of the squares of a set of numbers)
SEG	Similar Exposure Group
SIMTARS	The Safety in Mines Testing and Research Station was established in 1983 by the Queensland Government following the tragedies of the Box Flat Colliery and Kianga No 1 Colliery underground mine explosions
SPL	Sound Pressure Level
SSE	Site Senior Executive
STEL	Short-term exposure limit
Synaptopathy	Synaptic damage
TDI	Toluene diisocyanate
TEOMs	Tapered element oscillating microbalances
TGA	Therapeutic Goods Administration
TLV	Threshold limit value (established by the ACGIH)

Tmax	Exposure limit expressed in time (typically minutes), as for UV radiation exposure.
TTS	Temporary Threshold Shift, temporary hearing loss as a result of acoustic trauma (exposure to noise)
TWA	Time-weighted average
UCL	Upper Confidence Limit (refer to GCG website for explanation of how this is used in occupational hygiene data analysis and decision-making)
UFS	Ureaformol/Formophenolic Symptoms
UV	Ultraviolet
VDV	Vibration Dose Value
VOCs	Volatile organic compounds
VTV	Vibration Total Value, a measurement used in the evaluation of hand-arm vibration
VWF	Vibration White Finger – a vascular condition resulting from over-exposure to hand-arm vibration
WBV	"*Whole-Body Vibration*"—specifically referring to the iOS app. This report does not abbreviate "whole-body vibration" generally, and only uses the abbreviation, WBV, when referring to the name of the app.
WES	Workplace Exposure Standards
WHO	World Health Organization
WSHR	Workplace Safety and Health Regulation
ZOO	Zones of operation

Asbestos

4. Asbestos

4.1 Overview

Summary of the health effects presented by the risk

The health risks include lung cancer, mesothelioma (a rare form of cancer), asbestosis (a chronic progressive lung disease), pleural thickening (an abnormal build-up of fluid in the lining around the lungs), decreased lung capacity, and death.

What we know about the risk (available data and evidence from RSHQ and other sources)

In the workers' compensation (WC) data (2016 to 2021) provided by RSHQ there were six cases of mesothelioma:

- Three in Coal Mining
- One in Gas Supply
- One in Explosives
- One in Copper Mining

In addition, according to the RSHQ Mine Dust Lung Disease website there were two cases of asbestosis in the period 1984 to 2014. Of the seven cases of cancer reported five were mesothelioma and two were described more generically as 'lung cancer'.

RSHQ provided High Potential Incident (HPI) reports for the period 2015 to 2020. There were three instances where asbestos was reported: two in repairs/maintenance to buildings, and one where asbestos was identified in a load of waste material.

There is no indication of any exposure monitoring, nor the level of risk posed to workers.

Given the latency of asbestos related diseases it is likely that the WC data underreports occurrences of disease, especially amongst retired workers.

How we can learn more about the impact of this risk in the resources sector in Queensland

Given the WC data, and the ongoing reporting of asbestos related diseases in the wider community, we recommend that both exposure and health monitoring data continue to be collected and investigated by RSHQ across all inspectorates for current and past workers.

Asbestos is a hazard in the resource sector as it is both naturally occurring and present in man-made materials. Demolition workers, drywall removers, asbestos removal workers, firefighters, and automobile workers also may be exposed to asbestos fibres.

Asbestos is a group of naturally occurring fibrous silicate minerals which are composed of long and thin fibrous crystals, with each fibre being composed of many microscopic "fibrils" that can be released into the atmosphere by abrasion and other processes. The World Health Organization defines asbestos as "a naturally occurring mineral fibre that is resistant to heat, fire and chemicals". It was once widely used in a variety of products such as insulation, construction materials, and automobile brakes. But there has been a big push to get rid of it because scientists discovered that when people come into contact with it over time, their risk for lung cancer increases significantly.

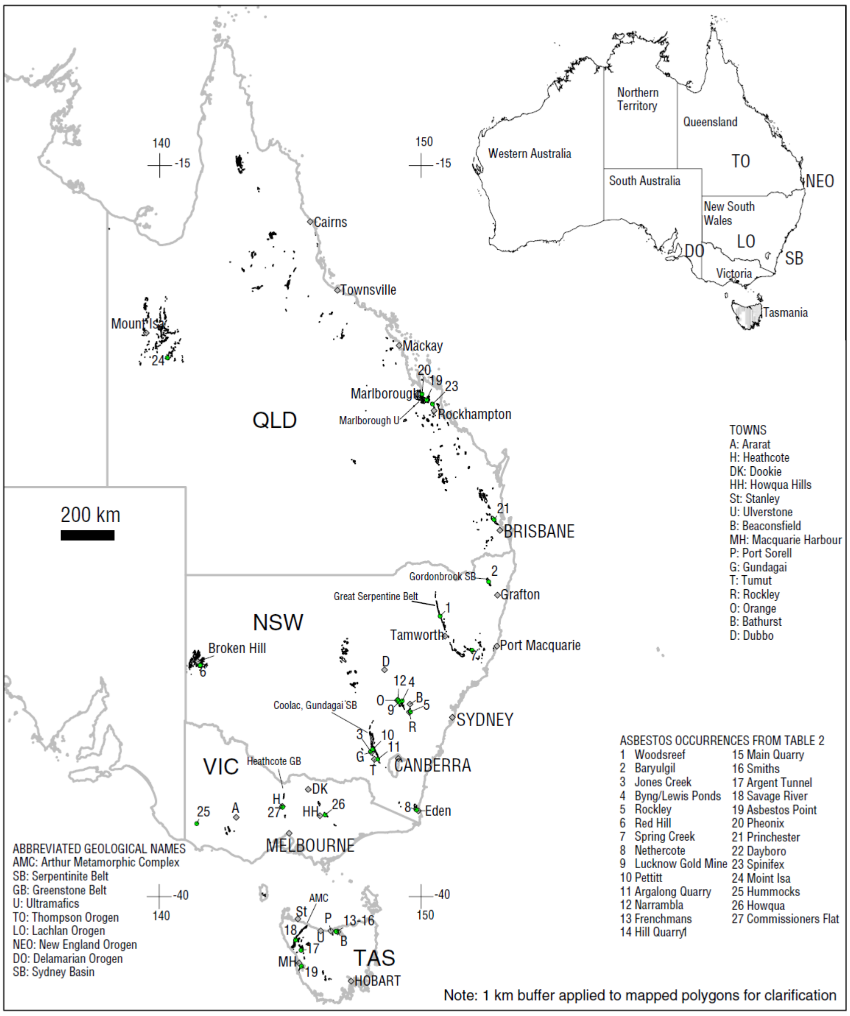
Australia began regulating asbestos products in the late 1970s. The use of crocidolite (blue) asbestos was banned in 1967, while the use of amosite (brown) asbestos continued until the mid-1980s. The ban on chrysotile (white) asbestos finally came about 20 years later, at the end of 2003.

Asbestos minerals are commonly found around the world in certain types of rock and soils including:

- Serpentine (chrysotile [white])
- Amphibole (actinolite, amosite [brown]
- Anthophyllite, crocidolite [blue] and tremolite

The map below outlines the occurrence of asbestos minerals in Eastern Australia (Hendrickx, 2009).

Figure 1: Map of occurrence of asbestos minerals in Eastern Australia.



4.2 What is the health hazard?

Inhalation is the main health hazard (very rarely contact absorption).

What are the health effects/consequences of exposure?

Health impacts are serious and potentially hard to detect as they can take many years to appear long after exposure has ceased:

- Cancer of the lung, ovary and larynx
- Mesothelioma – cancer of the lining of the lung
- Asbestosis
- Pleural plaques
- Decreased lung capacity

4.3 Who is exposed? And how are they exposed?

Asbestos is still widely in use in both industry and household products, despite being banned from use in 2003.

Historically workers may be exposed in asbestos mining (such as the Greenvale nickel mine which had serpentine bands that included chrysotile asbestos). However, currently the major risk to workers is exposure when doing building demolition or modification, drywall removal, or working on brake pads. See details on the Queensland Government Asbestos information website: https://www.asbestos.qld.gov.au/know-where-asbestos/naturally-occurring-asbestos

Asbestos exposure happens when microscopic asbestos fibres become airborne and are inhaled. In an ideal environment with little disturbance, it may take 48 to 72 hours for asbestos fibres to settle. If the dust is disturbed, it can easily become airborne again because it is so light.

4.4 What are the current QLD regulatory requirements for the management of the hazard?

The risk to workers of exposure to asbestos on mine sites is regulated via the Coal Mine Safety and Health Regulation (CMSHR) 2017 and the Mining and Quarrying Safety and Health Regulation (MQSHR) 2017. Workers not on mine sites are regulated by the Workplace Health and Safety Regulation (WHSR) 2011.

Work health and safety legislation regulates the management, control and removal of asbestos in the workplace (including residential premises which are a 'workplace' when work is undertaken by a contractor) for non-mine sites. Key legislation and codes of practice include:

- *Work Health and Safety Act 2011*
- *Work Health and Safety Regulation 2011, Chapter 8—Asbestos*
- *Code of Practice: How to Safely Remove Asbestos 2021 Workplace Health and Safety Queensland*

- *Code of Practice: How to Manage and Control Asbestos in the Workplace 2020, Workplace Health and Safety Queensland*

The last document above outlines a process to manage and control asbestos in the workplace through:

- Identifying if asbestos or asbestos containing material (ACM) is present at the worksite
- Creating a register of all asbestos or ACM
- Developing a management plan to control the risks associated with the asbestos or ACM
- Naturally occurring asbestos
- Contaminated sites
- Demolition and refurbishment work
- Asbestos related work
- Disposing of asbestos or ACM
- Managing exposure to asbestos or ACM
- Measuring the exposure
- Health monitoring
- Training workers
- Limited use of equipment
- Controlling the risks through applying the hierarchy of control priorities
- Removal
- Enclosing
- Encapsulating and sealing
- Tools and Equipment
- Safe work practices
- Personal protective equipment
- Laundering clothing
- Cleaning up

Public health legislation applies to asbestos-related activities carried out at non-workplaces settings (i.e. by homeowners at domestic premises).

- *Public Health Act 2005*

- *Public Health Regulation 2005*

Environmental protection and waste legislation regulate the transportation of commercial and industrial waste; the licensing of disposal facilities (such as landfills); and notification and remediation of contaminated land.

- *Environmental Protection Act 1994*
- *Environmental Protection Regulation 2008*
- *Environmental Protection (Waste Management) Regulation 2000*

The Department of Environment and Science maintains a public register of contaminated land (including land contaminated by asbestos). It also regulates the transportation and disposal of asbestos waste.

Both the CMSHR 2017 and MQSHR 2017 regulate the risks posed by naturally occurring asbestos that may be exposed during mining processes within the mining and quarrying industries and asbestos materials installed in buildings and plant on mine sites in very similar manners. Specific reference to managing the risk from exposure to asbestos is made in:

- *Mining and Quarrying Safety and Health Regulation 2017, Chapter 2, Part 14, Division 2 Sections 141 and 142*
- *Coal Mining Safety and Health Regulation 2017, Chapter 2, Part 12, Sections 88A and 88B*

The two sets of regulations are identical and contain sections dealing with:

- Asbestos material installed in buildings and plant
- Asbestos, other than asbestos material installed in buildings and plant, i.e. naturally occurring asbestos
- The regulations then defer the details to NOHSC code of practice for the safe removal of asbestos (NOHSC 2002) which has been replaced by the Safe Work Australia Code of Practice – How to safely remove Asbestos (Safe Work Australia, 2020)

Asbestosis is a notifiable disease under section 195 of the MQSHA 1999.

In all regulated sectors, the use of asbestos is prohibited for all uses unless exemptions are granted consistent with the *Model Work Health and Safety Regulation*—Chapter 8 (2011).

Exemptions exist for:

- Genuine research and analysis
- Sampling and identification in accordance with the regulation
- Maintenance of, or service work on, non-friable asbestos or ACM, fixed or installed before 31 December 2003, in accordance with these Regulations
- Removal or disposal of asbestos or ACM, including demolition, in accordance with these regulations

- The transport and disposal of asbestos or asbestos waste in accordance with jurisdictional legislation
- Demonstrations, education or practical training in relation to asbestos or ACM
- Display, or preparation or maintenance for display, of an artefact or thing that is, or includes asbestos or ACM
- Management in accordance with these regulations of in situ asbestos that was installed or fixed before 31 December 2003
- Work that disturbs asbestos during mining operations that involve the extraction of, or exploration for, a mineral other than asbestos
- Laundering asbestos contaminated clothing in accordance with these Regulations
- Work that is carried out in accordance with a prohibited asbestos notice issued under section 197B of the Act
- Applying a regulator approved method for managing the risk
- Soil that does not contain any visible ACM or friable asbestos in more than trace levels as per AS 4964:2004 (Method for qualitative identification of asbestos in bulk samples)

(Work Safe Australia 2011 updated 2021).

Building standards and approval legislation regulates building standards and approval processes through the *Building Act 1975*, including the demolition of buildings and structures which contain asbestos. Councils have the responsibility for administering this legislation.

- *Building Act 1975*
- *Building Regulation 2006*

4.5 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

As noted above Safe Work Australia have revised various NOHSC documents and issued them as model codes of practice.

The Asbestos Safety and Eradication Agency was established in 2013 to administer the National Strategic Plan. The *National Strategic Plan for Asbestos Awareness and Management* (NSP) aims to eliminate asbestos-related diseases in Australia by preventing exposure to asbestos fibres. The first phase of the plan from 2014 to 2018 aimed to:

- Increase public awareness
- Identify best practice
- Improve the capacity to identify the various forms of asbestos
- Identify priority areas of the removal of asbestos and ACM
- Commission appropriate research

- Provide leadership to promote the total ban on asbestos mining and manufacture worldwide

NSP 2019–2023 builds on the previous plan's progress. It complements and enhances existing asbestos policies, plans and actions at all levels of government. It recognises that governments and regulatory agencies, along with businesses, unions, individual organisations, advocacy groups, researchers and members of the community, all need to work together to support coordinated and more effective asbestos management.

The agency oversees national actions to improve asbestos awareness and the effective and safe management, removal and disposal of asbestos. The implementation of law remains the responsibility of the state governments and Safe Work Australia.

From 2010 all cases of mesothelioma have been collected by the Australian Mesothelioma registry from the state government cancer registries. Trends in mesothelioma cases are reported below.

According to Australia's National Dataset for Compensation Based Statistics, the workers who filed the most compensation claims between 2005 and 2008 included carpenters, electricians, power plant workers, plumbers, metal workers and telecommunication workers. Unfortunately, more recent data is not publicly available. In the resource sector it is most likely that those workers who undertake these types of tasks, are most at risk.

Safe Work Australia have established a web page for managing the risk associated with asbestos https://www.safeworkaustralia.gov.au/asbestos. This page references six model codes of practice:

- Construction Work
- Demolition Work
- How to Manage and Control Asbestos in the Workplace
- How to safely remove asbestos
- Managing the risks of plant in the workplace
- Safe design of Structures

4.6 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

The CMSHR 2017 and MQSHR 2017 do not explicitly state an exposure standard for asbestos material. They refer to NOHSC's document called 'Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment', [NOHSC:1003 (1995)] which has been superseded by the Safe Work Australia, (2019), *Workplace Exposure Standards for Airborne Contaminants*. Workplace Health and Safety QLD also defers to the Safe Work Australia Exposure Standards as outlined in the table below.

Table 1: Safe Work Australia—Workplace Exposure Standards Airborne Contaminants—2019.

Chrysotile	0.1 f/mL
crocidolite	0.1 f/mL
amosite	0.1 f/mL
other forms of asbestos	0.1 f/mL
any mixture of these	0.1 f/mL

f/mL refers to fibres per mL

In the USA the exposure standards recommended by OSHA, NIOSH and ACGIH are essentially the same as the Safe Work Australia values above with the addition of: "No worker should be exposed in excess of 1 fibre/cm^3 (excursion limit) as averaged over a sampling period of 30 minutes" NIOSH pocket guide to Chemical Hazards, Appendix C supplementary exposure limits website https://www.cdc.gov/niosh/npg/nengapdxc.html.

4.7 How is the hazard measured/evaluated in the workplace?

Current method and its limitations

The current method is the NOHSC (2005) Guidance note on the membrane filter method for estimating airborne asbestos fibres 2nd Edition. Testing agencies in Australia can be accredited by the National Association of Testing Authorities (NATA) to this method or to Australian Standard AS 4964-2004 for bulk samples.

This method uses an open-ended pumped filter to collect samples and then optical microscopy to count the fibres. This means that the sample can easily be contaminated with other dusts and not be able to be read.

The counting of fibres has been done using phase contrast microscopy (USEPA, 2021), transmission electron microscopy (USEPA, 2021), fluorescence microscopy (Ishida et al, 2010) and scanning electron microscopy (Gaggero et al, 2017).

The phase-contrast microscopy (PCM) membrane filter method does not have the capability to identify asbestos fibres specifically and, therefore, the fibre count will include other types of fibre and elongated particles that meet the shape and size criteria (e.g. organic, machine-made mineral fibres (MMMF), mineral cleavage fragments). This is relatively unimportant for monitoring workers in the licensed removal industry (or historically in the manufacturing industry) where the ACM will be the dominant fibre present. However, as the method is now used for monitoring other situations where there is no current and nearby work being carried out on ACMs, the PCM fibre count is increasingly unlikely to be representative of the asbestos fibre concentration (HSE, 2021).

Emerging technology/research

As described above, research has focussed on improving the technique used to count the fibres collected on the filter. A Web of Science literature search did not find any articles offering alternate technologies.

In a study by Ilvaska et al (2005) several immune system parameters were assessed in workers (n = 61) with at least 5 years' exposure to asbestos at an industrial plant. Workers exposed to asbestos fibres had significantly increased levels of immunoglobulin E and concentrations of interleukin-6 and -8 in comparison with two sets of controls (in-plant and town control groups). The levels of soluble adhesion molecule ICAM-1 were higher in the exposed group compared to the town control group. Significantly increased levels of IgA were found in asbestos-exposed group in comparison to the town control. Evaluation of the expression of adhesion molecules on lymphocytes, monocytes and granulocytes by flow cytometry showed significant increases in the class of selectins CD62L on monocytes and granulocytes. Moreover, significantly increased expression of markers CD69 and CD66b on eosinophils was found among workers exposed to asbestos. In conclusion, exposure to asbestos fibres was found to have several effects on immune system. Alterations of these immune parameters may indicate hypersensitivity (increased levels of IgE, increased expression of activation markers CD66b and CD69 on eosinophils) and an elevated inflammatory status (increased levels of interleukins—IL-6, IL-8) in exposed workers.

Vlˇckovác et al (2009) developed a sensitive assay method for a parallel, rapid and precise determination of the most prominent oxidative stress biomarkers: 8-iso-prostaglandin F2, malondialdehyde and 4-hydroxynonenal in body fluids of patients with asbestos or silica-induced lung diseases. We have included this reference for its potential usefulness in designing an asbestos surveillance program.

What health monitoring data is currently available to RSHQ?

Cases of MDLD reported to RSHQ for all mining include two cases of asbestosis reported for the period 1984 to 2014, and none since. Seven cancer cases have been reported to RSHQ since 1984, including five that were mesothelioma and two that were more generic lung cancer.

What is the status of the data/issues with the data?

No exposure monitoring data was provided by RSHQ.

In the workers' compensation data (2016 to 2021) provided by RSHQ there were six cases of mesothelioma:

- Three in Coal Mining
- One in Gas Supply
- One in Explosives
- One in Copper Mining

Other cancers were not reported in the WC data supplied.

4.8 What does it tell us about workers' exposures?

The reported cases appear to relate to asbestos in materials rather than naturally occurring asbestos, because the disease cases are being reported for maintenance-type workers. There were no details on the cases to make any assessment.

How could data collection and management be improved?

No health surveillance monitoring data could be provided by RSHQ (e.g. air monitoring data that would be collected during periods of potential asbestos exposure). Work Safe Australia have issued a guide for medical practitioners on the types of information to be collected where health monitoring is required for hazardous chemicals (Work Safe 2013, updated 2020).

Routine medical surveillance is required under the CMSHR 2017 and MQSHR 2017. As part of this assessment, in addition to investigating the respiratory capacity of the worker and obtaining x-rays where required, the worker history and current occupation in relation to potential exposure to asbestos is noted. This is also true for the medical assessment of past workers.

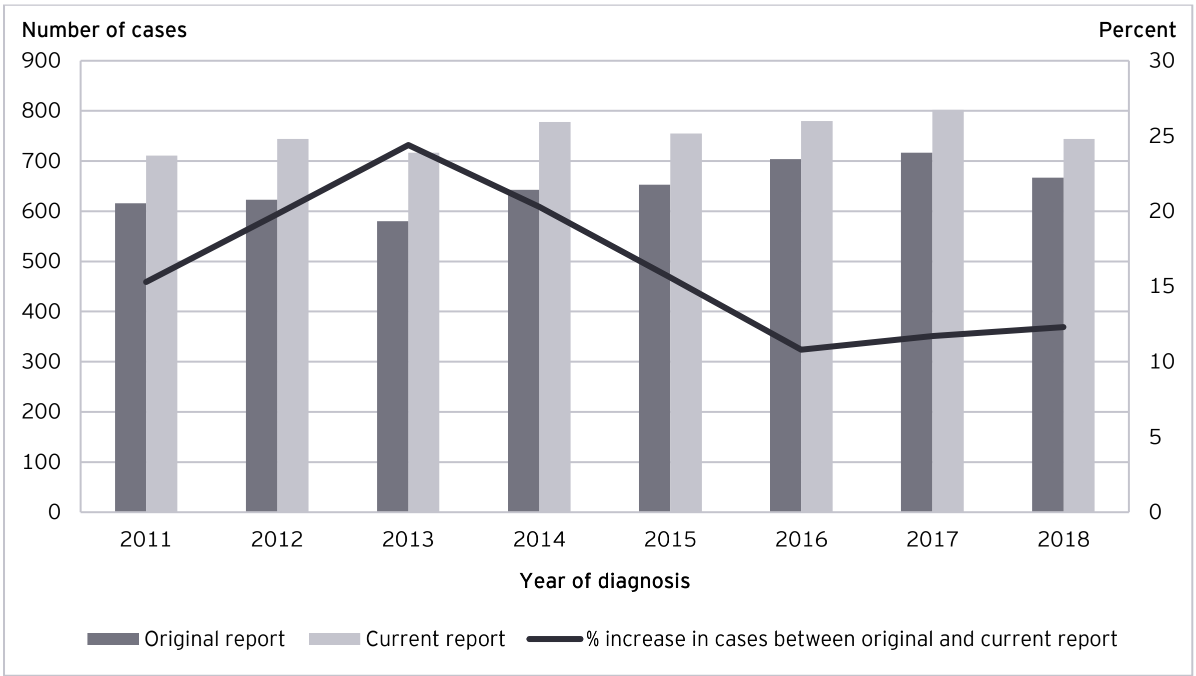
RSHQ provided High Potential Incident (HPI) reports for the period 2015 to 2020. There is a requirement to report any HPI involving exposure to a hazardous material. There were three instances where asbestos was reported: two in repairs/maintenance to buildings and one where asbestos was identified in a load of waste material. There is no indication of any exposure monitoring, nor the level of risk posed to workers.

4.9 What other exposure data is available/in peer reviewed literature?

Historical data

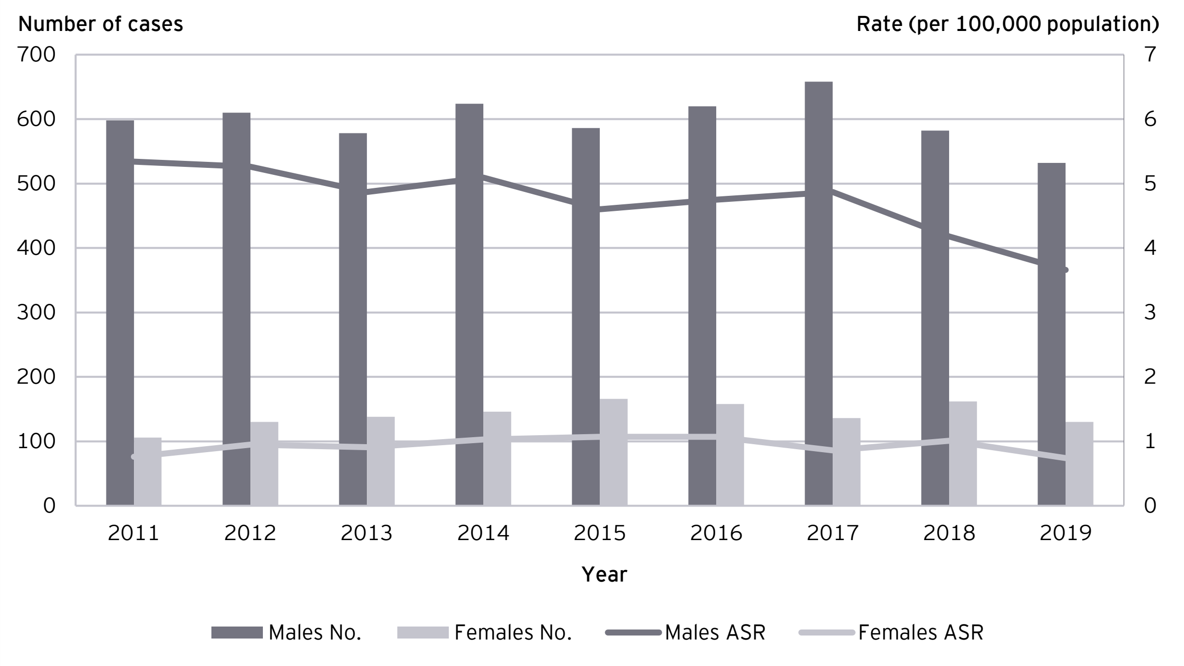
The following graphs from the report, *Mesothelioma in Australia 2019*, by the Australian Institute of Health at Work (AIHW), for Safe Work Australia, illustrate the overall prevalence of the disease and the occupations most associated with work related disease. Approximately one third of cases were related only to non-work activities. Most (40 -50 %) were a combination of work and non-work activities. This illustrates that despite the ban on the use of asbestos and ACM since 31 December 2003 the number and rate of mesothelioma cases remains relatively constant, which suggest that mesothelioma will likely be serious problem for many years to come, due to the latency of the disease.

Figure 2: Difference in number of mesothelioma cases between original and current report during 2011 to 2018



Sources: AMR 2012, 2013, 2014, 2015, 2016, 2017; AIHW 2018b; AIHW 2019; AIHW analysis of AMR data at 1 April 2020; Table A1 in Mesothelioma in Australia 2019 – data tables.

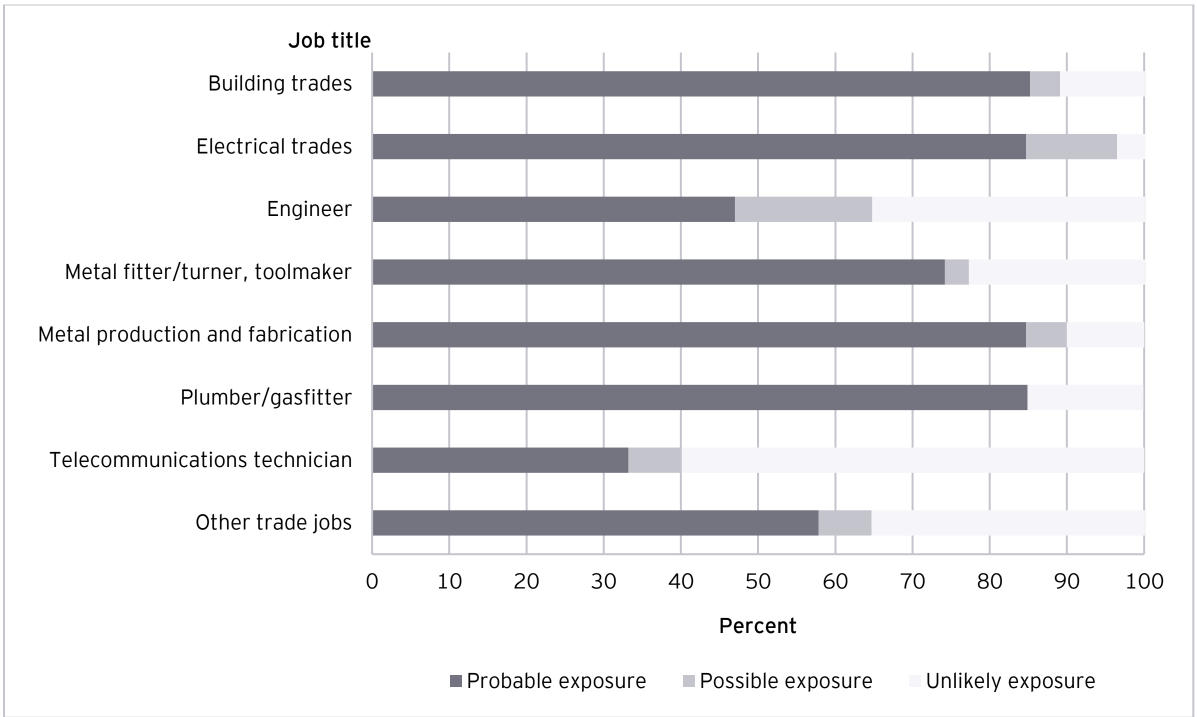
Figure 3: Number and age-standardised rate (per 100,000 population) of people diagnosed with mesothelioma, by year and sex, 2011 to 2019



Note: Rates have been age-standardised to the 2001 Australian Standard Population.

Source: AIHW analysis of AMR data at 1 April 2020; Table A2 in Mesothelioma in Australia 2019 – data tables.

Figure 4: Occupational asbestos exposure by job title for the 'Trades' module, 2010–2019

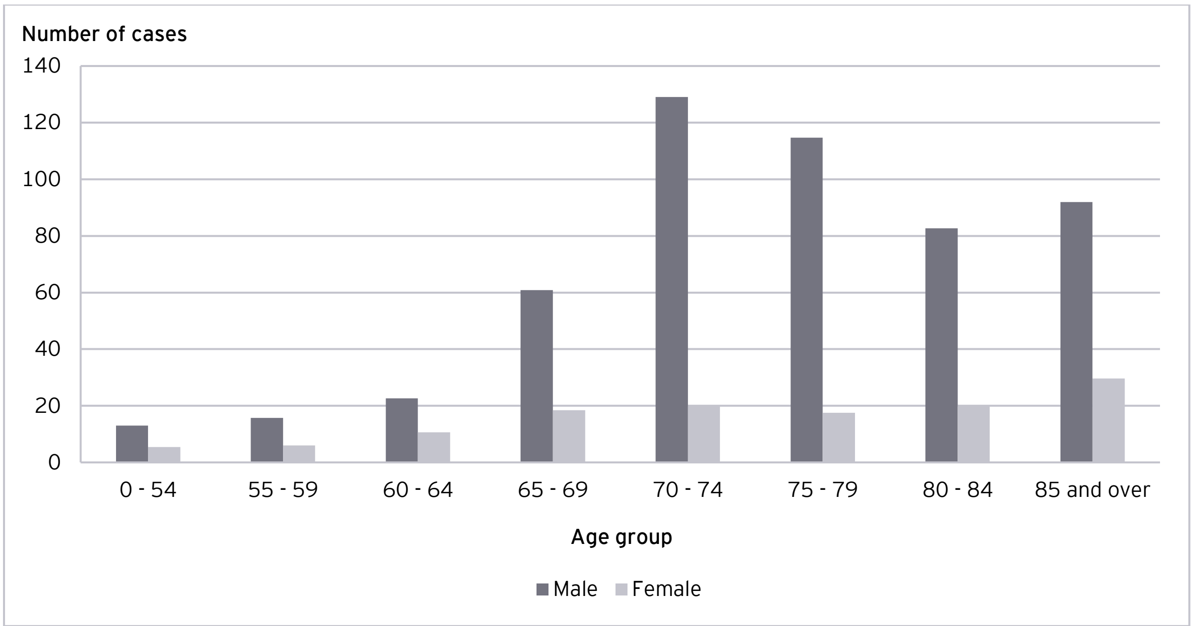


Source: AIHW analysis of AMR data at 1 April 2020; based on interviews completed among people who were diagnosed with mesothelioma between 1 July 2010 - 31 December 2019; Table A8 in Mesothelioma in Australia 2019 – data tables.

Current data

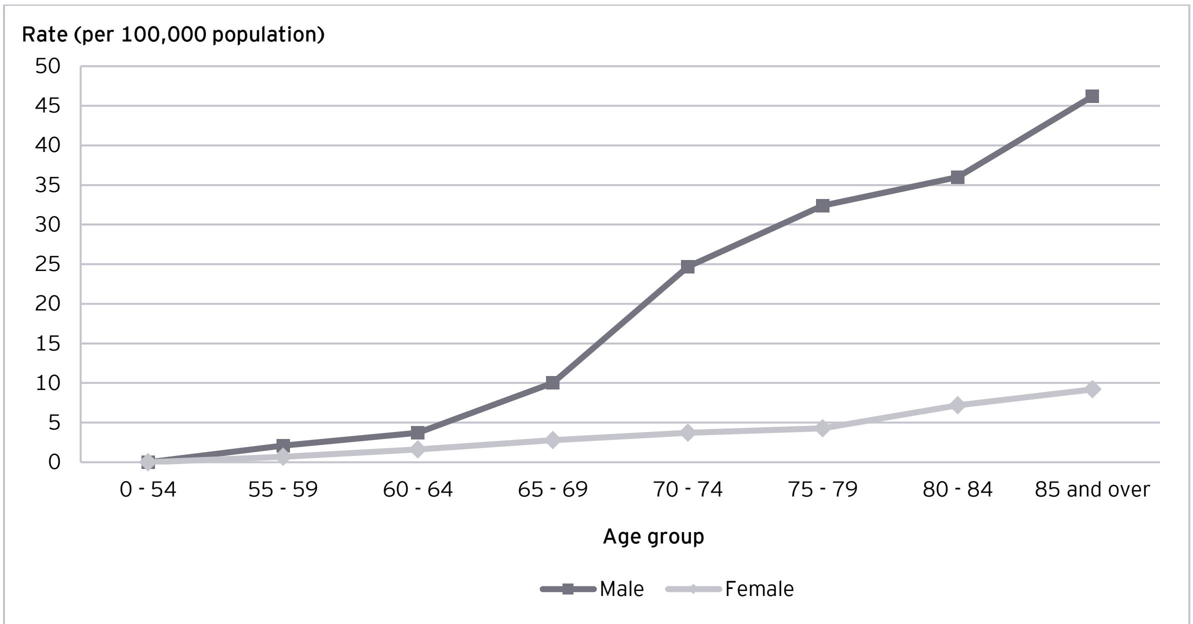
Data for 2019 was available from the AIHW report. The first diagram shows number of cases by age group, and the second is a diagram showing rate of cases per 100,000 population. Most cases are in elderly males (65 +), which is accentuated when consideration of the number people in the population in these age groups are taken into account.

Figure 5: Number of people diagnosed with mesothelioma, by age group and sex, 2019



Source: AIHW analysis of AMR data at 1 April 2020; Table A4 in Mesothelioma in Australia 2019 – data tables.

Figure 6: Rate (per 100,000 population) diagnosed with mesothelioma, by age and sex, 2019



Source: AIHW analysis of AMR data at 1 April 2020; Table A4 in Mesothelioma in Australia 2019 – data tables.

Australia imposed a total ban on the mining, manufacture and use of asbestos on 31 December 2003. However, as can be seen from the graphs above, the incidence of mesothelioma is not reducing significantly. This is no doubt due to the long latency period of the disease (up to 60 years (Cancer Council of Australia, 2021)). It suggests that more effort should be made on the early detection of the disease as though there is no cure for the disease, early treatment can extend the period of control over the disease, improving both quality of life for the patient and life expectancy (Cancer Council of Australia, 2021).

4.10 References

2. 29CFR (2021) Code of Federal Regulations 29, part 1901.1001—Asbestos, Standard https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1001 accessed 18 June 2021

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Blast fumes

5. Blast fumes

5.1 Overview

Summary of the health effects presented by the risk
Workers exposed to the post blasting plume may suffer: ► Eye irritation and coughing ► Initial dizziness and/or headache ► Shortness of breath, asthma ► Cyanosis (blue lips, fingertips) onset up to 8 hours later ► Pulmonary oedema ► Chronic effect due to obliterative bronchiolitis – the smallest air passages (bronchioles) are seriously scarred and become distorted & blocked ► Serious lung inflammation (pulmonary oedema) has been known to develop several hours after exposure to very high levels of NO2 ► Fatality is possible at high concentrations of fume and in poorly ventilated areas
What we know about the risk (available data and evidence from RSHQ and other sources)
Current data supplied by RSHQ does not fully allow the assessment of the health hazards from blast fumes, due to gaps in the data as outlined below. The HPI database for the period 2011-2020 listed 135 incidents where blast fume was recorded. In 71 cases the fume travelled beyond the blast exclusion zone, in 27 cases workers were either exposed to fume or had to seek protection inside a building to avoid exposure. In most cases the exposure was very short term as the plume dispersed. No personal monitoring of blast fume was reported, though, as part of the blast monitoring fixed monitors were usually deployed. On seven occasions workers (number not specified on most occasions) received medical treatment for exposure to blast fume (details not specified).
How can we learn more about the impact of this risk in the resources sector in Queensland?
A better understanding of the exposure of workers to blast fume would be obtained through a detailed analysis of incidents where people are exposed to blast fume including utilising atmospheric dispersion modelling to assess the concentration and duration of exposure. Reports of workers requiring medical treatment should be investigated.

5.2 What is the health hazard?

Exposure of workers to post blast fume primarily containing nitrogen dioxide (NO_2) and nitric oxide (NO), occasionally carbon monoxide (CO), nitrous oxide (N_2O), ammonia, nitric acid, and carbon dioxide.

5.3 What are the health effects/consequences of exposure?

Exposure to NO_2, nitric acid and CO particularly, can cause:

- Eye irritation and coughing
- Initial dizziness and/or headache
- Shortness of breath, asthma
- Pulmonary oedema
- Chronic effect due to obliterative bronchiolitis – the smallest air passages (bronchioles) are seriously scarred and become distorted & blocked
- Cyanosis (blue lips, fingertips) onset up to 8 hours later
- Serious lung inflammation (pulmonary oedema) has been known to develop several hours after exposure to very high levels of NO_2
- Fatality is possible at high concentrations of fume and in poorly ventilated areas

5.4 Who is exposed? And how are they exposed?

There is potential exposure for any worker (in coal, metal mines, quarries, petroleum, and gas) who is caught in the post blast plume. The focus tends to be on the blast crew, however most people affected by blast fume tend to be general mining workers. This can occur when people enter an area where a blast has occurred before the plume disperses or if the wind direction changes from what's expected and the plume travels in an unpredicted direction. The harm may be created through inhalation, absorption through skin or eyes.

5.5 What are the current QLD regulatory requirements for the management of the hazard?

Exposure to hazardous substances is covered in the mining health and safety regulations and the workplace health and safety legislation. Use of explosives in open cut coal mines is governed by *Explosives for use, or used, at a surface mine must be stored, used and disposed of under AS 2187 'Explosives—Storage, transport and use'* (section 115 CMSHR, 2017).

Standard operating procedures and related controls governing the storage, transport and use of explosives are required for open cut coal mines (Chapter 3, Part 4) and underground coal mines (Chapter 4, Part 6) (CMSHR, 2017).

For non-coal mines Chapter 2—Subdivision 2—Blasting Procedures details how to ensure safe use of explosives including requiring the mine to develop procedures (MQSHR, 2017).

Australian Standard AS21872.-2006 Explosives Storage and use: Part 2: Use of Explosives contains details on the safe usage of explosives including Blast Management Plans (Appendix A).

See Guidance note QGN20—Management of oxides of nitrogen in open cut blasting. Significant fume incidents must be reported using the RSHQ fume reporting template and are logged as high potential incidents. QGN20 provides details on how to prevent and manage blast fume.

QGN-10 =Handling explosives in Surface Mines and Quarries and QGN 11 – Handling explosives in Underground Mines, provides advice on the safe use of explosives in mines and quarries, particularly in relation to ensuring personnel are not affected by the blast fume through the establishment of exclusion zones and restricting access to the area until the site has been examined and declared safe to enter.

A significant fume event must be notified to the Explosives Inspectorate immediately and formal notification via the incident notification form must be lodged within 24 hours. If the incident occurs on a mine site, then the mines inspectorate must be notified as well. The Explosives Act and regulation does not directly apply to Occupational Health risks, they are managed via are the various OHS acts and regulations (CMSHA, 1999, CMSHR, 2017, MQSHA, 1999, MQSHR, 2011, WSHR, 2011).

Blast fume information including:

- Links to RSHQ guidance material
- Fume reporting templates
- Overview of the characteristics of blast fumes
- Tolerable exposure
- Symptoms of overexposure
- Responding to exposure
- Preventing exposure
- Reporting blast fume incidents
- Resources to assist in managing blast fumes

can be found via the weblink: https://www.business.qld.gov.au/industries/mining-energy-water/explosives-fireworks/requirements/blasting/blast-fumes

5.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

In NSW under the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014* [NSW] there is a requirement to develop and implement an Explosives control plan.

The operator of a mine or petroleum site at which there is a risk to health and safety associated with explosives or explosive precursors at the mine or petroleum site must prepare an explosives control plan for the mine or petroleum site that sets out the means by which the operator will manage those risks in accordance with clause 9.

The Explosives control plan includes the requirements:

1. *An explosives control plan must set out the control measures for risks to health and safety associated with explosives at the mine or petroleum site taking into account:*

    a. *The potential for unintended or uncontrolled detonation of explosives,*

b. *The characteristics of relevant explosives and the purposes for which they are to be used,*

c. *The characteristics of the places in which the explosives are to be used,*

d. *The full set of phases for the use of relevant explosives such as the charging and firing phases,*

e. *The potential for explosives to deteriorate,*

f. *The potential for the theft or misuse of explosives,*

g. *The potential for the ejection of fly rock or other material as a result of the detonation of an explosive*

In Western Australia the *Dangerous Goods Safety (Explosives) Regulations 2007* (Explosives Regulations) require the preparation of a blast plan and written blast records before an explosive is used to blast rock or similar solid material, or to damage, destroy or demolish anything, whether on or under land or water. There is guidance material issued under both the *Dangerous Goods Safety (Explosives) Regulation 2007* and *Mines Safety Inspection Act 1995*. Guidance material includes the *Guide to Blast Plan Preparation, Including Mining Operations, 2013*. This guide and its associated templates assist the mining industry and other blasting operations to prepare a blast plan and records about the blast that address the key requirements of regulations 129, 130 and 134 of the Explosives Regulations. They are based on sections A2 and A3 of Australian Standard AS 2187.2

Explosives—Storage and use—Use of explosives. The Explosives Regulations are invoked in regulation 8.1A of the *Mines Safety and Inspection Regulations 1995*. Comments related directly to the use of explosives in mining have been italicised in brown in this guide.

In addition to the various regulatory approaches the Australian Explosives Industry and Safety Group Inc. has released several codes of practice relating to blasting including:

- Prevention and Management of Blast Generated NOx Gases in Surface Blasting

This details the possible sources of NOx from blasting and controls. It references Acute Exposure Guidelines Levels (AEGL) for the public as a function of exposure time spanning from 10 minutes to 8 hours and utilises a three tier AEGL in terms of severity of response.

- Blast Guarding in an Open Cut Environment

5.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

Table 2, from QGN 20, cites the Safe Work Australia exposure standards for these gases in the workplace.

Table 2: Blast fume gas exposure standards

				ACGIH	NIOSH	OSHA	Worksafe NZ	HSE
	TWA	STEL	IDLH					
NO_2	3 ppm	5 ppm	20 ppm	TWA 0.2 ppm	STEL 1 ppm	5 ppm	TWA 1ppm	TWA 0.5 ppm STEL 1 ppm

				ACGIH	NIOSH	OSHA	Worksafe NZ	HSE
	TWA	STEL	IDLH					
NO	25 ppm	None specified	None Specified	25 ppm	25 ppm	25 ppm	25 ppm	2 ppm
CO	30 ppm	None specified	None Specified		TWA 50 ppm STE: 200 ppm	TWA 50 ppm	TWA 25 ppm STEL 200 ppm	TWA 20 ppm STEL 100 ppm
CO_2	12 500 ppm (coal mines) 5 000 ppm elsewhere	30 000 ppm	None specified	TWA 5 000 ppm STEL 3 000 ppm	TWA 5 000 ppm STEL 3 000 ppm	TWA 5 000 ppm	TWA 5 000 ppm STEL 3 000 ppm	TWA 5 000 ppm STEL 3 000 ppm

Note TWA is denoted as the long-term exposure limit concentration and STEL is denoted as maximum exposure limit concentration under the CMSH Regulation Schedule 6.

5.8 How is the hazard measured/evaluated in the workplace?

5.8.1 Current method and its limitations

The RSHQ hazards database references blast fume under Air Quality, citing the controls as being:

- Weather/wind direction and
- Location of personnel and equipment
- The operator is required to include the management of potential harm from blast fumes within the safety management system

In open cut mines, **Guidance Note QGN 20 Management of oxides of nitrogen in open cut blasting**, provides guidance on the safe use of explosives to minimise blast fume production.

Fume is generated when explosives are detonated and react in non-ideal reactions. The current management of the hazard focusses on optimising the blast conditions to minimise fume generation and the prediction of the area impacted by any fume (the Fume Management Zone (FMZ)) and the path of any cloud of blast fume to avoid contact with workers using appropriate atmospheric plume dispersion modelling.

In addition, the manufacture and storage of explosives is monitored to ensure that the fume generating potential is minimised e.g. water resistance, storage in well ventilated areas under cover away from sunlight, minimising prill degradation and fines generation, minimising temperature cycling, keeping within the design shelf life of the product, using approved initiating devices.

The severity of a plume, which is an indirect measure of the concentration of the constituent pollutants, is measured on a six-point scale based upon nature of the appearance of the plume. This can be assessed remotely without placing personnel in the plume.

Table 3: Plume severity ratings

Level	Description	Pantone number
0	No fume just dust	Warm Grey IC
1	Fume just visible	Pantone 155C

Level	Description	Pantone number
2	Minor yellow/orange fume	Pantone 157C
3	Moderate orange fume	Pantone 158C
4	Significant orange fume	Pantone 1525C
5	Major red/purple fume	Pantone 161C

QGN 20 Annex H includes pictorial descriptions of each level to assist in the classification.

If personnel are exposed to the fume or require unplanned evacuation to avoid exposure or the fume breaches the FMZ or leaves the lease the Explosives and Mines Inspectorate must be notified.

There is no similar detailed guidance for underground mines.

In a study carried out in 2011- 2015 by JKTech at the request of the Fume Steering Group created by the Chief Inspector of Explosives, 5035 blasts were analysed. Overall, 57 % rated level 0, 17 % rated level 1, 12 % rated level 2, 8 % rated level 3, 5 % rated level 4 and 1 % rated level 5.

For underground mines, Guidance Note QGN 11, *Handling Explosives in Underground Mines* provides some assistance in the safe operation of explosives. Personnel are excluded from the blasting area until after the post blast environment has been inspected and the area has been declared safe to enter, by the shotfirer.

The area inspected by the shotfirer would include using personal monitoring devices to monitor the gas concentrations.

There have been several safety bulletins and alerts issued by RSHQ dealing with blast fume issues including:

- Explosives safety alert no. 44—15 March 2011—Prevention and management of blast fumes—highlights the need for a blast fume management plan that includes health and medical management plans. It aimed to raise awareness of the risk for the potential for oxides of nitrogen (NOx) to be generated during an ammonium nitrate-based blast. It lists known causes of NOx during a blast, including the impact of wet conditions which caused a total of 24 people to require treatment and hospital observation. It focusses on preventing the generation of NOx by adhering to the correct conditions, as well as predicting potential exposure through understanding the meteorology and having a health management plan to treat any exposures including seeking medical advice from a medical adviser.
- Mines Safety Bulletin no. 61 28 March 2007—Flammable and toxic gases in open cut coal mines. This describes the potential hazards created by the blast fume gases and recommends:
  - Regular review of the safety and health management system, specifically focussing on the effective implementation of Standard Operating Procedures
  - Training of supervisors and all mining personnel including:
    - Gas awareness training
    - Locations where the potential for flammable and toxic gases may accumulate
  - How to safely control the hazard

- Mine Safety Alert no. 269—28 June 2011—Potential contamination of underground mine ventilation by blast fumes generated at an open cut mine draws attention to an incident where the wind carried the blast fume from an open cut mine to nearby the ventilation intakes for an underground coal mine. It recommended that:
  - The open cut blast plans note the location of any nearby underground coal mine and associated intakes including the distance involved
  - The blast plans consider wind direction and strength as well as blast history and characteristics
  - Communication and liaison with the underground mine to allow for evacuation if required
  - Blasting should be postponed if the underground mine is likely to be affected
  - The underground mine Emergency Response Process Hazard Management Plan includes managing a blast fume risk

5.8.2 Emerging technology/research

Low fume explosives

Araos M et al. (2018) report on a study to replace ammonium nitrate explosives with hydrogen peroxide-based explosives and thus remove the generation of NOx. They demonstrated the feasibility of using this explosive.

Improved water resistance

Explosives manufacturers offer a range of modified ANFO explosives that are not sensitive to water ingress. For example, Orica offer a product Fortis Extra (Orica, 2021).

Development of testing facilities capable of testing the fume potential of ammonium nitrate-based explosives.

Mainiero (1997) describes work carried out at NIOSH in developing a facility that allowed for detonating large, confined charges in a controlled volume. The facility was used to determine the fumes produced by the detonation of a variety of ANFO formulations and commercial explosives.

5.9 What health monitoring data is currently available to RSHQ? (for each industry sector)

Workers' compensation statistics do not directly identify any compensable diseases due to blast fume though there are seven cases of other respiratory conditions due to substances listed in the WC statistics provided over the period 2016 to 2021, as well as a number of cases relating to other respiratory conditions not associated with CWP, asbestos or silica.

5.10 What is the status of the data/issues with the data? (What does it tell us about workers' exposures?)

As described above and below there is very limited information relating to the exposure of workers to blast fume other than that events do occur and occasionally the worker(s) require medical treatment. None of the reported incidents where workers required medical treatment appear to be reported as safety alerts or bulletins. The workers' compensation data supplied did not have sufficient granularity to identify if there were any cases due to blast fume.

5.11 How could data collection and management be improved?

A better understanding of the exposure of workers to blast fume would be obtained through a detailed analysis of incidents where people are exposed to blast fume including utilising atmospheric dispersion modelling to assess the concentration and duration of exposure. Reports of workers requiring medical treatment should be investigated.

5.12 What other exposure data is available/in peer reviewed literature?

There appears to be very little exposure data available, the paper by Mainiero et al in 2007 noted that there were no direct measurements of the concentrations of gases in the post explosion fume, a Web of Science search revealed no publications, and no data was available on the NIOSH website. The focus has been on preventing the fume and predicting where it will travel.

Explosives Inspectorate Safety Alert 44 – Prevention and Management of blast fumes, notes that from 1992 to 2002 there were eight post-gas events in the USA that resulted in health-related injuries to workers.

The NIOSH website Mining Topic – Blasting and Explosives notes that between 1994 and 2005 there were eight miners injured by exposure to blasting fumes. By comparison 32 were injured due to flyrock (NIOSH, 2021).

Bakke et al (2001) note that in tunnel workers exposed to up to 20 ppm of NO_2 after blasting there was a short-term loss in lung function.

NIOSH has undertaken extensive research aimed at reducing or eliminating the production of toxic gases from blasting. The emphasis was on ensuring that entry into areas where blasting has occurred is prevented until after the area has been inspected and determined to be safe through measurement of the airborne concentrations of potential hazardous gases. (See for example: https://www.cdc.gov/niosh/mining/coversheet514.html and https://www.cdc.gov/niosh/mining/topics/explosives.html)

There are examples of fixed monitoring in underground metal mines being used to determine when it is safe to re-enter a blast zone (D. Bahrami et al, 2019).

Computer models have also been developed to assist in the calculation of the time necessary for safe re-entry after a blast in an underground metal mine (C.M. Stewart, (2014)).

Remote sensing of the nitrogen dioxide concentration in blast plumes has been trialled (M. I. Attalla et al, (2008).

5.12.1 Historical data

RSHQ did not provide any personal exposure monitoring information relating to blast fume. There were no identifiable lost time injuries in the RSHQ database over the period 2011 to 2020.

The HPI database for the period 2011-2020 listed 135 incidents where blast fume was recorded. In 71 cases the fume travelled beyond the blast exclusion zone, in 27 cases workers were either exposed to fume or had to seek protection inside a building to avoid exposure. In most cases the exposure was very short term as the plume dispersed. No personal monitoring of blast fume was reported, but fixed monitors were usually deployed as part of the blast monitoring. On seven occasions workers (numbers not specified on most occasions) received medical treatment for exposure to blast fume (no details of medical treatment).

5.12.2 Current data

A deidentified Health Risk Assessment for an open cut coal mine was reviewed. Unfortunately blast fume only merits a paragraph on page 26 where it states *that discussion with Technical Services personnel who control and monitor the blast fume indicated a high level of awareness of this topic*. In the qualitative risk assessment, the only work groups rated with any level of risk (low) were the open-cut examiners (OCEs) and the blast crew, and no further assessment was undertaken.

A deidentified Health Risk Assessment carried out at a gold mine focussed on personal exposure monitoring and does not include blast fume.

A Health Risk Assessment report undertaken in November 2017 at an open cut coal mine again focussed on occupational hygiene and personal exposure monitoring and did not assess blast fume as a health hazard although NO_2 from all sources is identified as a potential hazard with a level 4 (out of 5) ranking (major risk). In the Health Risk Assessment, however, it is rated as 3 moderate and likelihood 2 giving a risk rank of 9, when the control was applied, the likelihood is reduced to 1 and the rank to 6, though the risk is ranked as uncertain and the priority for gathering more information was set at 12—though it is not clear what this means. There is a statement under section 7.4 Blast Crew—*There is potential for exposure to blasting fume, although blasting management procedures should control incidental exposures on a day-to-day basis.*

A Health Risk Assessment for a proposed underground coal mine provided by RSHQ for this study did not consider blast fume.

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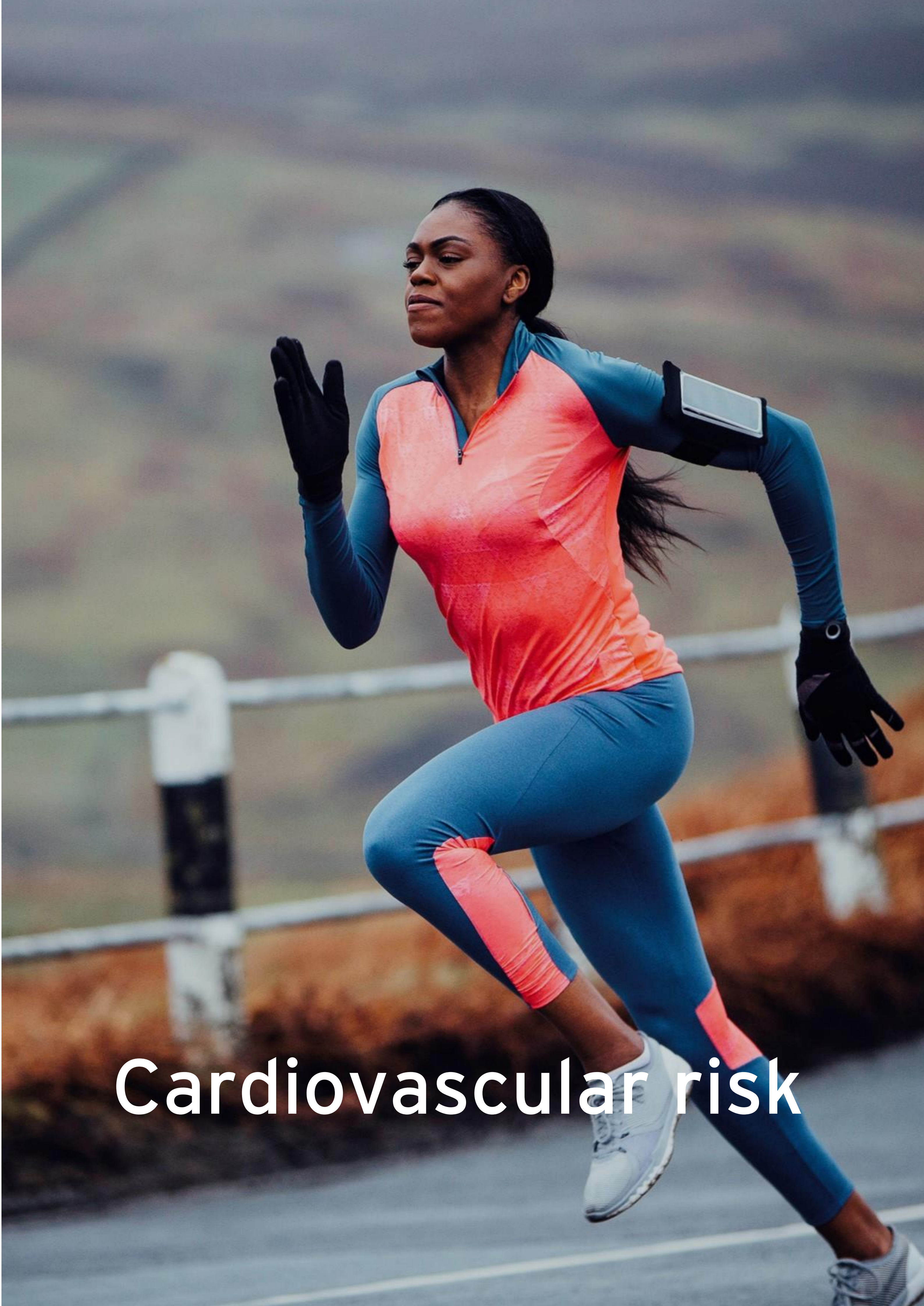

Cardiovascular risk

6. Cardiovascular risk

6.1 Overview

Summary of the health effects presented by the risk
Cardiovascular Disease Risk (CVD risk) in this review is defined as an individual experiencing symptoms and consequences relating to the heart and major vessels not receiving enough oxygen, most commonly chest pain or discomfort, mild to severe pain or immediate cardiac arrest. This condition occurs most often during exertion or excitement when the heart requires greater blood flow. The effects of CVD are wide-ranging, often debilitating and potentially fatal. The most common symptom of ischaemic heart disease is chest pain, or discomfort, which is known as angina. Stable angina is pain that occurs when your heart works harder (such as during exercise) but settles with rest. Unstable angina occurs even at rest and is indicative of a medical emergency. The pain may be associated with breathlessness and nausea. The symptoms of cardiovascular disease can cause impairment in the workplace, and in rare circumstances fatal consequences.
What we know about the risk (available data and evidence from RSHQ and elsewhere)?
There is evidence suggesting that resources workers generally experience greater CVD risk, largely due to controllable lifestyle factors. According to the Australian Bureau of Statistics 2014-15 National Health Survey [16], mining and resource workers have higher rates of smoking, physical inactivity, harmful alcohol consumption, obesity levels, and inadequate fruit and vegetable consumption compared to the national average and other industries [16]. Multiple studies have found higher rates of ischaemic heart disease among male tradespersons, labourers and/or plant and machine operators and drivers compared with other occupations. Risk exposure varies between industries; research from the United States has linked employment in the coal mining industry to increased risk of death via CVD. In Australia, Monash Health Watch data from the Oil and Gas industry suggests that due to increased health monitoring, oil and gas workers may be at up to 20% lower risk than the general population in experiencing death due to CVD [31]. Workers within Metals, Mining and Quarries face increased CVD risk through increased exposure to potentially toxic elements.
How we can learn more about the impact of this risk in the resources sector in Queensland
The Cardiovascular Risk Management Guidelines for the NSW Coal Industry, part of the NSW coal industry health surveillance scheme, outline a consistent methodology for managing workers who have been identified with elevated cardiovascular risk factors through a medical screening (Order 43), within the NSW coal industry. These risk management guidelines may serve as a proven framework for managing CVD risk on an individual level [23].

6.2 What is the health hazard?

Cardiovascular diseases (CVD) involve the heart or blood vessels. Among the many conditions that make up CVD are ischaemic (or coronary) heart disease, stroke (damage to the brain caused by a blood clot or intracerebral bleeding), and other diseases of the heart such as arrhythmia, cardiomyopathy, and heart valve problems.[1] Work-related cardiovascular disease is caused by occupational factors that increase the oxygen requirements of the heart or decrease the capacity of the heart to use oxygen.[2]

Often there is no clear-cut cause for a particular cardiac event. Both occupational and non-occupational factors might contribute to the development of underlying CVD. Because of this, it can be very difficult to link an acute cardiovascular event (such as angina, a heart attack, or an arrhythmia) to a single work-related factor. Many factors both within and outside of work influence when a person experiences such an event. Practically, this can mean that:

- Occupational exposures can make an important contribution to a person developing CVD, but the person might have a heart attack whilst not at work
- A person might have a heart attack at work because of CVD that developed due to non-work exposures
- Strenuous work activity might precipitate a heart attack in a person who has underlying CVD that is not related to work

For the remainder of this review, 'CVD risk' refers to a risk of symptoms secondary to ischaemic heart disease unless otherwise specified. This is because ischaemic heart disease is the most common CVD present in the Australian population. Ischaemic heart disease refers to a condition whereby the heart does not get enough oxygen. This is usually due to blockages within the blood vessels that supply the heart.

CVD risk is therefore defined as an individual experiencing symptoms and consequences relating to the heart not receiving enough oxygen, most commonly chest pain or discomfort mild to severe pain or immediate cardiac arrest. This condition occurs most often during exertion or excitement, when the heart requires greater blood flow.

6.3 Occupational exposures within the resources sector

6.3.1 Chemical hazards

Certain chemicals, metals, gases, and physical agents present in workplaces have been causally linked to increased CVD risk and mortality.[2-5] These include:

- **Solvents** including carbon disulphide, halogenated hydrocarbons and chlorofluorocarbons (usually arrhythmogenic effects [6]) and methylene chloride
- **Exposure to potentially toxic elements** found in ore deposits including arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), thallium (Ti), uranium (U), and zinc (Zn)
- **Gases** including carbon monoxide, cyanide, and hydrogen sulphide
- **Exposure to particulate matter (dusts)** such as coal dust, metalliferous dust, and silica dust. Exposures to increased ambient particulate matter and fine particulates (PM 2.5) are linked to increases in cardiovascular morbidity and mortality, with finer particles posing an increased risk
- **Other chemical hazards** including nitroglycerin, diesel exhaust and organic combustion products

Workers are generally exposed to these hazards through inhalation, ingestion, or skin contact. The mechanisms of how exposure to each of these hazards increases CVD risk vary from increases in physiological stress, reductions in blood pressure, disruption to functioning of the central nervous system to decreases in blood oxygenation.[2]

6.3.2 Physical hazards

Environmental factors that contribute to increased risk of CVD and/or CVD mortality include:

- **Noise:** Exposure to noise places increased stress on the body, through increased activation of the parasympathetic nervous system. Occupational noise exposure is strongly associated with hypertension once noise levels exceed 85 dB(A) and weakly associated with increased risk of mortality from CVD.[7]

- **Vibration:** Vibration has been associated with peripheral vascular disease, caused by hand/arm vibration, associated with the use of vibrating tools such as air hammers and chain saws.[2]

- **Temperature:** Temperature can refer to both ambient temperatures created through weather conditions or the location of a site, or heat/cold generated with equipment (such as welding), clothing and PPE, and activities which increase core temperature. Temperature extremes have been associated with an increased risk of CVD, especially in individuals with pre-existing conditions.[2]

- **Sudden, heavy physical exertion:** Long periods of relatively low physical activity combined with sudden periods of intense physical activity increases risk of CVD complications.[2]

- **Electricity:** An electric shock may cause cardiac arrythmias, or even cardiac arrest

6.3.3 Work-related hazards

Factors relating to the way that work is conducted that contribute to increased CVD include the following. These are present in the design of several occupations in the resources sector, with psychosocial hazards and risks explored in more detail in chapter 12.

6.3.4 Shift work

Shift work, in particular night work, has been linked to increases in CVD risk. Shift workers are up to 40% more likely to experience CVD as compared to those with regular schedules.[8]

6.3.5 Sedentary work

Sedentary work has been linked to increased CVD risk. Research indicates that in 2016, 40 per cent of Australian adults did not meet the physical activity guidelines of 150 minutes of moderate intensity physical activity per week and 50 per cent of Australian workers reporting they sit often or all the time at work.[9]

6.3.6 Exposure to psychosocial hazards:

Exposure to psychosocial hazards increases CVD risk primarily through the mechanism of increased physiological and psychological stress. Psychosocial factors that have been linked to increased CVD risk include high job demands, low support, low control, a lack of job security and negative co-worker interactions such as bullying and harassment. [2, 5, 10]

Negative workplace climate and culture has also been linked to increased CVD risk, with people working in a poor psychosocial safety culture being 59% more likely to develop a new CVD over a 5-year period than those with a positive psychological safety climate. [11]

Imbalances between effort and reward in a role have been causally linked to increased CVD risk. In an 11 year longitudinal study, research showed that workers in jobs where there is an imbalance between effort and reward are 26% more likely to develop coronary heart disease than their peers. [12] In a 24-year longitudinal study, workers with high effort-reward imbalance roles were 140% more likely to develop CVDs than their peers. [13]

6.3.7 Individual and lifestyle hazards

Approximately 90% of the risk of myocardial infarction (commonly known as heart attacks) observed worldwide can be attributed preventable and/or easily treatable lifestyle factors, such as smoking, raised blood pressure, type 2 diabetes, obesity, psychosocial factors, physical inactivity and inadequate intake of fruits and vegetables. [14, 15] Below outlines some of these individual factors in more detail.

6.3.8 Overweight and obesity

The effects of overweight and obesity are widely recognised as one of Australia's leading health concerns and are a leading driver of CVD risk. In 2014–15, 27.9% of adult Australians were obese (body mass index [BMI] ≥30 kg/m^2), with a further 35.5% being classified as overweight (BMI = 25–29.9 kg/m^2). [16] Overweight and obesity are linked to increased risk of death from CVD. [17] Data on the prevalence of overweight in the Queensland resources sector is not available; it can be assumed that the prevelence of overweight is at least comparable to, if not greater than, the general population.

Measuring the waist circumference is a less commonly used clincial tool, but it has been consistently related to the risk of developing coronary heart disease, and this remains statistically significant after adjusting for BMI. This is suggestive of a negative effect of abdominal adiposity, which is also linked with diabetes, high blood pressure and mortality. [32]

Diet, particularly diets high in fat and sugar and low in low energy foods such as vegetables and fruit are a major contributor to overweight and obesity. An increase in sedentary lifestyles, opportunities to exercise and participate in sporting activities and co-morbid conditions (such as Type 2 Diabetes) also contribute to increased risk of weight gain.

Stress has also been linked with increased weight, through lack of energy and motivation as well as increased food consumption (e.g. emotional or comfort eating), which may indirectly contribute to weight gain. [18]

6.3.9 Demographics

Age and gender have been linked to increased risk of CVD; males experience up to six times higher risk of CVD than females [19], and individuals over 45 experience increased risk that further increases with age. Location of living also influences CVD risk, with those living rurally or remotely experiencing higher risk due to economic, social, and educational factors that can reduce quality of diet and access to care. [20]

Aboriginal and Torres Strait peoples experience increased risk of CVD, even at BMI values considered to be within a "healthy" range. Individuals from culturally and linguistically diverse backgrounds may have rates of obesity higher than the Australian average. [18] Socioeconomic disadvantage has also been linked to increased CVD risk. [15]

6.3.10 Smoking

Tobacco smoking is a major cause of CVD risk, with current smokers experiencing increased risk of virtually all types of CVD. Over one third of CVD deaths and one quarter of acute coronary syndrome hospitalisations in Australia aged < 65 can be attributed to smoking. Individuals who smoke have a threefold increased risk from dying from CVD compared to people who have never smoked and double the risk of death from a heart attack, heart failure or stroke. The risks appear to diminish with quitting, with excess risks largely avoided by quitting before age 45. [21]

6.3.11 Use of illicit drugs

Many illicit substances increase risk of cardiovascular disease. The use of cocaine in particular has been linked to increased CVD risk, through well-recognised toxic effects on the heart and cardiovascular system. [22] Cannabis has multiple effects on the cardiovascular system, although more research is needed to consistently demonstrate adverse health outcomes. [34]. Long term methamphetamine usage appears to be associated with significant cardiac morbidity, and even sporadic use may exacerbate pre-existing heart conditions. [33]

6.3.12 Co-morbid illnesses

Several illnesses have been linked to increased CVD risk, including diabetes, chronic renal disease, sleep apnoea and high blood cholesterol. [23] Some of these illnesses can be prevented or improved by modifying the above lifestyle factors.

6.4 What are the health effects/consequences of exposure?

The effects of CVD are wide-ranging, often debilitating and potentially fatal. Cardiovascular disease is a leading cause of death in Australia. Over 43,000 deaths were attributed to CVD in 2017 [24] with ischaemic heart disease remaining the leading cause of mortality in Australia. [25]

The most common symptom of ischaemic heart disease is chest pain, or discomfort, which is known as angina. Stable angina is pain that occurs when your heart works harder (such as during exercise) but settles with rest. Unstable angina occurs even at rest and is indicative of a medical emergency. The pain may be associated with breathlessness and nausea.

Cardiac conditions associated with poor heart function may present with breathlessness, fatigue or swelling. Other important symptoms of CVD include *syncope* – a sudden loss of consciousness with spontaneous recovery; and *cardiac arrythmia* – an irregular beating of the heart that in severe cases may result in loss of consciousness. [26] These symptoms can place worker health at risk and compromise their ability to perform tasks safely.

CVD poses a risk for those workers in safety critical roles. The sudden onset of syncope caused by CVD can potentially result in a serious incident should an equipment operator or similar become incapacitated due to a cardiac event. HPI data provided by RSHQ [29] indicates 75 incidents deemed non work related where operators were found unconscious or died suddenly. While these events have been classified as ‘non work related', this chapter outlines factors which may possibly have exacerbated an underlying condition or gave rise to pathology that could be diagnosed as CVD. Additionally, it is highly likely that more events than reported have occurred within the resources sector workforce. If these events occurred away from the workplace, they would not be reported as work related, even if workplace factors contributed to the event in question.

In summary, the symptoms of cardiovascular disease can cause impairment in the workplace, and in rare circumstances fatal consequences.

6.5 Who is exposed? And how are they exposed?

An estimated 1.2 million (5.6%) Australian adults aged 18 years and over had 1 or more conditions related to heart or vascular disease, including stroke, in 2017–18.[20] In 2017–18, the prevalence of heart, stroke and vascular disease among adults was higher among men (6.5%) than women (4.8%) and increased with age: 1.0% of people between 18-44 had reported a cardiovascular disease, while more than 1 in 4 (26%) of those aged 75 and over had done so. Approximately 1.4 million Australians are also at a high risk of having a heart attack or stroke in the next five years.[15]

CVD is a prominent health risk in the resources sector. According to the Australian Bureau of Statistics 2014-15 National Health Survey, when compared with all other industries, mining and resource workers have higher rates of smoking, physical inactivity, harmful alcohol consumption, obesity levels, and inadequate fruit and vegetable consumption compared to the national average. [27]

Multiple studies have found higher rates of ischaemic heart disease among male tradespersons, labourers and/or plant and machine operators and drivers compared with other occupations. [5] In a longitudinal study of oil and gas workers, obesity rates doubled between 2000 and 2010 (from 10-19%) while obesity rates increased only 1% in the general population. [28]

6.5.1 How risks may vary across sectors

CVD risk is present for workers across all resources sectors, but occupational risk factors for CVD may vary significantly across sectors due to the differing nature of work.

Within the coal mining industry, research from the United States has linked employment in the coal mining industry to increased risk of death via CVD disease. [29] Other research has linked long-term exposure to coal dust to increased risk of CVD. and mortality due to CVD.

Research from SIMTARS in 2001 found no direct link between employment in the coal mining industry and cardiac disease but noted elevated risk factors that may contribute to cardiac-related mortality in the future, such as increased rates of smoking, obesity and problem drinking.[30] Within this same sample, coal miners had a significantly higher blood pressure than baseline population which is a risk factor for increased CVD.

Within the oil and gas industry, there is evidence to suggest that due to increased frequency of examinations by a medical practitioner, oil and gas workers may be at lower risk than the general population in experiencing death due to CVD. Health Watch data, a longitudinal study of the health effects of working in the petrochemical industry, reported a risk of CVD up to 20% lower than the general population in a 2018 report. [31]

Within the metals, mining and quarries industry, workers are more likely to be exposed to toxic metalliferous elements through mining, rock cutting and smelting activities. Exposure to elements such as arsenic, lead, cadmium, and copper is associated with an increased risk of cardiovascular disease. [32] Given this workforce is exposed to the same overall individual and occupational risk factors as those in other sectors, it is possible the risk of CVD is greater in this cohort, however, this has not been quantified in peer reviewed literature.

6.6 What are the current QLD regulatory requirements for the management of the hazard?

6.6.1 Regulation

Regulation of CVD risk is distributed indirectly across multiple pieces of legislation, including legislation pertaining to noise, dust, fumes, hazardous chemicals, and other physical risks outlined in other chapters of this report. A review of these pieces of legislation are in the appropriate sections of the overall report.

The ***Coal Mining Safety and Health Regulation*** (2017) states that "A coal mine's safety and health management system must provide for controlling risks at the mine associated with other physical or psychological impairment" which could include pre-existing cardiovascular disease. In addition, the same regulations state, "A health assessment may include matters not covered in the health assessment approved form if a risk assessment has been carried out for a task for which a person is, or is to be, employed by the employer; and having regard to the risk assessment, the appointed medical adviser considers the person needs to be assessed in relation to the additional matters to achieve an acceptable level of risk." This could include individual assessment of cardiovascular fitness for a specific task, after a risk assessment has been undertaken.

The ***Mining and Quarrying Safety and Health Regulation*** 2017 has detailed requirements for hazard assessment, risk analysis, reduction, and monitoring. These would apply to cardiovascular risks. It also covers the requirements for assessment of the fitness level of workers for their duties.

Workplace Health and Safety Queensland considers prolonged sitting a hazard, partly due to the increased risk of CVD. As such, employers or persons conducting a business or undertaking (PCBUs) must manage the risks of identified hazards according to the WHS Act. While individual health is not explicitly a focus area for the regulator [30], Workplace Health and Safety Queensland has also provided several pieces of guidance for employers and employees on improving health and wellbeing within the workplace.

6.6.2 Health surveillance

Within Queensland, coal miners submit to the Coal Mine Worker's Health Surveillance scheme. This collects information by questionnaire on potentially relevant previous exposures, including solvents, heat, and noise. In addition, the background medical history is questioned including history of heart disease, surgery, angina, or blackouts. During the physical examination, some cardiovascular risk screening factors including height and weight (from which BMI can be calculated) and blood pressure are recorded. There is also an examination of the cardiovascular system, and the process allows for an electrocardiogram (ECG) to be carried out if indicated by the findings. A blank version of the current medical screening form used for this assessment was provided as part of this review, but no accompanying epidemiological data were provided.

Those engaged in mines rescue must complete an annual or 2 yearly VO2 max step test, in additional to the Coal Mine Workers' Medical assessment. More stringent criteria are applied to mines rescue workers for their medical assessment, compared with the general coal mining population. [31]

Health surveillance within the metals, mining, and quarries sector is required based on the site operator's assessment of risk, only respiratory health surveillance is mandated by regulation. Some data relevant to cardiovascular disease is collected (height, weight, smoking history) but the purpose does not include cardiovascular risk assessment.

There is no mandated standardised assessment directly measuring the risk of a future cardiac event currently required in either health surveillance program.

6.6.3 Workplace controls

The following workplace controls are often implemented to lower CVD risk:[5]

- Implementation and enforcement of non-smoking policies. This appears to be an effective way to decrease direct as well as second hand occupational exposure to tobacco smoke, which is a large CVD risk
- Prevention of exposure to carbon monoxide. This type of exposure comes largely from vehicle exhausts, but can occur in other situations
- Prevention of exposure to other potentially hazardous chemicals. This may be achieved through several engineering or administrative controls, or with personal protective equipment (PPE) where appropriate
- Prevention of exposure to noise through engineering controls, administrative controls, and the use of PPE where appropriate
- Prevention of exposure to psychosocial risk factors in the workplace
- Optimising shift design to assist shift workers in maintaining a healthy diet and transitioning effectively between shifts and non-shifts from a sleep perspective

Workplaces also often implement health promotion programs, as the worksite has been promoted as a very important place for basing health promotion activities. However, uptake on these programs is often limited. [5]

Organisations rarely introduce controls specifically to protect against CVD risk, however many of the controls they implement do indirectly mitigate this risk. The most effective way to reduce CVD risk is through targeting individual modifiable lifestyle factors amongst workers. This will also encourage a healthier working population, reducing impacts of other common diseases including respiratory conditions and obstructive sleep apnoea.

6.7 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Given that up to 90% of CVD risk is attributable to preventable factors, much of the risk management focuses on individual risk factors as opposed to direct controls for occupational hazards. This section outlines the most common ways of managing risk from an individual perspective.

6.7.1 NSW – Health Surveillance of Coal Miners

The Cardiovascular Risk Management Guidelines for the NSW Coal Industry, part of the NSW coal industry health surveillance scheme, outline a consistent methodology for managing workers who have been identified with elevated cardiovascular risk factors through a medical screening (Order 43), within the NSW coal industry. [23]

These risk management guidelines include guidance for employers and medical professionals, as well as agreed standards, risk thresholds with associated actions for employers.

6.7.2 Australian chronic disease prevention alliance – Absolute cardiovascular risk assessment

Promoted by the Heart Foundation, an absolute CVD risk assessment (or Heart Health Check) is an integrated approach that brings together the cumulative risk of multiple cardiovascular risk factors to estimate the combined risk of experiencing a heart attack or stroke in the next five years. This five-step risk assessment process involves a doctor conducting a health screening on history, risk factors, current risk, risk management and ongoing care requirements.[15] This assessment tool has been incorporated into the Order 43 medical required for coal mine workers in New South Wales. [23]

This integrated approach is likely to have an increased impact due to the cumulative effects of multiple risk factors. Creating even a moderate reduction in several risk factors is more effective in reducing overall CVD risk than a major reduction in a single CVD risk factor alone.

6.7.3 Pre-employment fitness assessments

Some organisations in the resources industry include cardiovascular risk scoring, or fitness testing, as part of a pre-employment health assessment for prospective workers. These assessments are more common in larger employers. This is done under a workplace policy, and the requirements, outcomes, and criteria for a determination of fitness will vary between employers. Using these assessments to make judgement on fitness for work is challenging and requires expert knowledge and, ideally, industry standards to allow an evidence-based and consistent approach. As such, the effectiveness of these fitness assessments is inconsistent.

6.7.4 International Association of Oil and Gas Producers (OGP) – Guidance Document

In 2013, a guidance document titled *"Prevention of heart attacks and other cardiovascular diseases—A guide for managers, employees and company health professionals"*[33] was published to provide guidance for the industry on managing cardiovascular risk, focusing primarily on reducing the impact of lifestyle factors on the risk. Among actions recommended by the report are the implementation of health assessments and screening; awareness, education, and training; promotion of risk factor reduction, such as smoking prevention and reduction, healthier diets, increased physical activity, stress prevention and reduction, and fatigue management. One suggestion in this regard is that the industry should consider involving the families of its workers in the reduction of CVD risk through the provision of initiatives, such as family fitness days, promoting healthy diets and lifestyles.

6.7.5 Primary physicians

Most of the risk management of CVD risk sits with primary care physicians. Given that CVD is largely preventable, Australian and overseas primary care guidelines emphasise comprehensive risk assessment to enable effective management of identified modifiable risk factors through lifestyle changes (e.g. weight management, smoking cessation and increased physical activity).[34]

From an evidence-based perspective, the most effective risk management strategies for reducing CVD risk involve managing excess weight, through strategies such as reduced caloric intake, increased physical activity and other measures to support lifestyle changes (such as quitting smoking). [18] These strategies are largely individual-based, with healthcare professionals acting as a support system by recommending strategies and providing continuing support.

6.7.6 What are the current exposure standards?

Quantifying current exposure standards for CVD is challenging, given the array of potential hazards.

For many risks (such as dust and noise), there are occupational limits defined by relevant legislation. Relevant bodies produce guidance and best practice how to manage other contributing factors to CVD risk such as psychosocial risk and fatigue. These factors will inform best practice in job design, in a way that reduces many worker health risks (including CVD).

From a medical perspective, there are several clinical guidelines and evidence-based indicators for which workers may be at increased risk of CVD. There are also guidelines for how and when individuals should receive treatment and interventions to manage this risk on an individual level.

Despite this understanding of the risk, it remains challenging to determine whether a workplace is "adequately" controlling CVD risks for their workers. The multi-faceted, highly individualised and intercorrelated nature of CVD risk proves challenging when trying to quantify whether any one workplace, is likely to expose individuals to dangerous levels of CVD risk.

A common clinical indicator for CVD is monitoring body mass index (BMI). BMI is a weight-for-height index that is commonly used to classify underweight, overweight and obesity in adults. It is the main measure used in international obesity guidelines and is recommended by the World Health Organization. [35]

Other clinical indicators include monitoring waist circumference, monitoring for hypertension (high blood pressure), dyslipidaemia (blood lipid levels that are too high or low) and glycaemia (blood sugar levels). Medical screenings will routinely monitor BMI and may also include waist circumference.[35]

6.8 How is the hazard measured/evaluated in the workplace?

It is challenging to isolate single, specific work-related exposures when determining the source of cardiovascular disease in an individual person. This is because of issues of latency between exposure and onset of illness, multiple possible risk factors, lack of specific work-related features that determine risk, and various factors that influence diagnosis.

Multiple causal factors contribute to CVD. It has been estimated that 64% of Australians have three or more modifiable risk factors. [35] Assessment of CVD risk on the basis of the combined effect of multiple risk factors (absolute CVD risk) is more accurate than the use of individual risk factors, because the cumulative effects of multiple risk factors may be additive or synergistic. [15]

Assessment of cardiovascular risks in workplaces occurs at an individual level, conducted by a medical professional. This assessment will include obtaining a history of symptoms which can impinge on effective job performance (e.g. chest pain, shortness of breath), blood pressure readings and self-reported symptoms and activities that contribute to CVD. [36]

Occupational physician guidelines do not recommend routine risk factor screening [36] for cardiovascular risk factors, as several risk factors occur in the general population for cardiovascular disease and there is incomplete information as to how this information translates directly to the risk of a CVD-related incident occurring at work. Regulated standards for medical assessments vary in their approach to cardiovascular risk. The Austroads "*Assessing Fitness to Drive*" standards state, "Routine screening for these risk factors is not required for licensing purposes, except where specified for certain commercial vehicle drivers as part of their additional accreditation or endorsement requirements. However, when a risk factor such as high blood pressure is being managed, it is good practice to assess other risk factors and to calculate overall risk. This risk assessment may be helpful additional information in determining fitness to drive, especially for commercial vehicle drivers".

Australian Health Assessment standards for rail safety workers [37] require cardiac risk scoring for Category 1[1] workers only. The standard states, "Category 1 workers are the highest level of Safety Critical Worker. These are workers who require high levels of attentiveness to their task and for whom sudden incapacity or collapse (e.g. from a heart attack or blackout) may result in a serious incident affecting the public or the rail network. Single-operator train driving on the commercial network is an example of a Category 1 task."

General duty of care provisions in the Queensland CMWHS Act, the Queensland Mining Health and Safety Act, and the Queensland WHS Act, extend to ensuring workers are fit for the duties they are to perform. Fitness for duty provisions in the Coal Mine Health and Safety Regulations (2017) focus on fatigue, and alcohol and other drugs. The Mining and Quarrying Safety and Health Regulation (2017) requires SSEs to ensures workers undertake a fitness for work assessment prior to commencing work, but the assessment criteria are not specified in the Regulations.

6.9 What health monitoring data is currently available to RSHQ? (for each industry sector)

As per other non-physical risks (such as psychosocial hazards), workers' compensation data are the main source of data from which CVD is measured. From the "Accepted Disease Claims in Mining Data", 7 of a total of 2706 workers' compensation claims involved cardiovascular symptoms. However, workers' compensation data are known to seriously underestimate the true extent of disease prevalence, particularly in illnesses with long latency between exposure to risk and onset of illness.[38]

Other LTI and HPI data lack sufficient detail to determine any trends or levels of exposure. 75 out of a total of 1975 high potential incidents (Form 1A) may have involved cardiovascular symptoms, however report data often only indicates that an employee was transferred to a medical facility with little follow up. 12 of the 13 5A incident reports directly reference CVD or could be inferred to be related to CVD ("Heart attack; suspected heart attack; loss of consciousness; natural causes").

Health surveillance data from the coal mining industry is available to RSHQ but could not be readily made available to researchers through the process of this review due to its paper based format.

[1] Category 1 workers are the highest level of Safety Critical Worker. These are workers who require high levels of attentiveness to their task and for whom sudden incapacity or collapse (e.g. from a heart attack or blackout) may result in a serious incident affecting the public or the rail network. Single-operator train driving on the commercial network is an example of a Category 1 task.

6.10 What other exposure data is available/in peer reviewed literature?

Coal miners have an increased risk of heart disease when compared to the general population, with the injury/disease incidence rates four times those of the All Industries data collected in Zeman (2007). [39] This has also been shown in the USA where the risk extended to people living in coal mining areas, suggesting environmental risk factors contributing to increased risk. [40]

A longitudinal Swedish study showed that there was an increased risk of death from ischaemic heart disease among miners, as well as other silica exposed workers, that could not be explained by smoking rates. [41]

In general, the evidence suggests that the increased health monitoring that has been implemented by petroleum and gas operators for workers in the petroleum industry is effective because they have better overall health than the Australian community, and are less likely to die from heart disease than the general population. [31]

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Diesel particulates

7. Diesel particulates

7.1 Overview

Summary of the health effects presented by the risk

Diesel particulate matter (DPM) was declared a Class I carcinogen by the WHO in 2012 and an occupational exposure limit (OEL) should be set for DPM rather than just a recommended limit. The health hazard for DPM is the inhalation of diesel exhaust which includes particulate matter, aerosols, and gases. There can be both acute and chronic effects from exposure to DPM.

- Short term exposure to high concentrations of DPM can cause headache, dizziness, and irritation of the eye, nose, and throat severe enough to distract or disable miners and other workers.
- Prolonged DPM exposure can increase the risk of cardiovascular, cardiopulmonary, and respiratory disease, and lung cancer.

What we know about the risk (available data and evidence from RSHQ and other sources)

A standard shift adjustment methodology should be set to calculate exceedances. In recent years, many mines have stopped applying shift adjustments and have reverted to 0.1 mg/m^3.

Atmospheric exposure monitoring data for elemental carbon is available for the underground coal mines. The exposures for the longwall move and outbye supply SEGs have decreased but are still not well controlled.

How we can learn more about the impact of this risk in the resources sector in Queensland

DPM monitoring should be extended across more parts of the RSHQ portfolio. No data was available for MMQ, explosives, or Petroleum and Gas. Underground metalliferous miners should also be monitored for exposure to diesel.

The use of biological monitoring for exposure to diesel engine exhaust should be investigated.

7.2 What is the health hazard?

Inhalation of diesel exhaust which includes particulate matter, aerosols, and gases. These include submicron liquid aerosols, and gases (vapours) such as CO, CO_2, NOx, SO_2 and hydrocarbons.

Diesel particulates are typically less than 1 micron in size, making them smaller than most other respirable dust found in underground mines. DPM aerosols often behave similarly to the surrounding gases and have much longer residence times in the atmosphere than the respirable dust particles. Due to their small size, a larger portion of diesel particles are deposited in the respiratory tract than the larger dust particles [1].

Figure 7: Graphical depiction of the composition of diesel particulate matter [1].

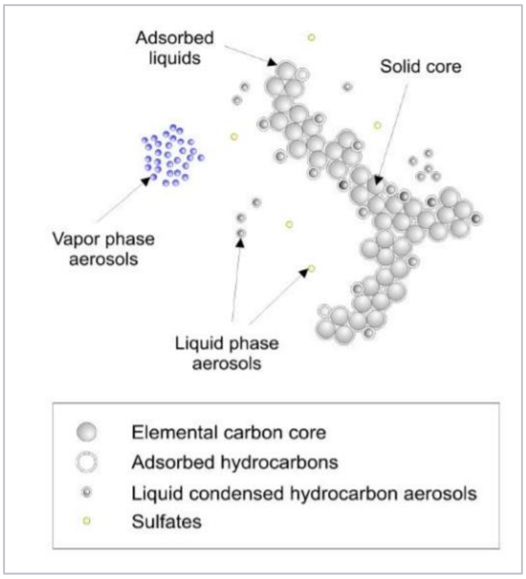
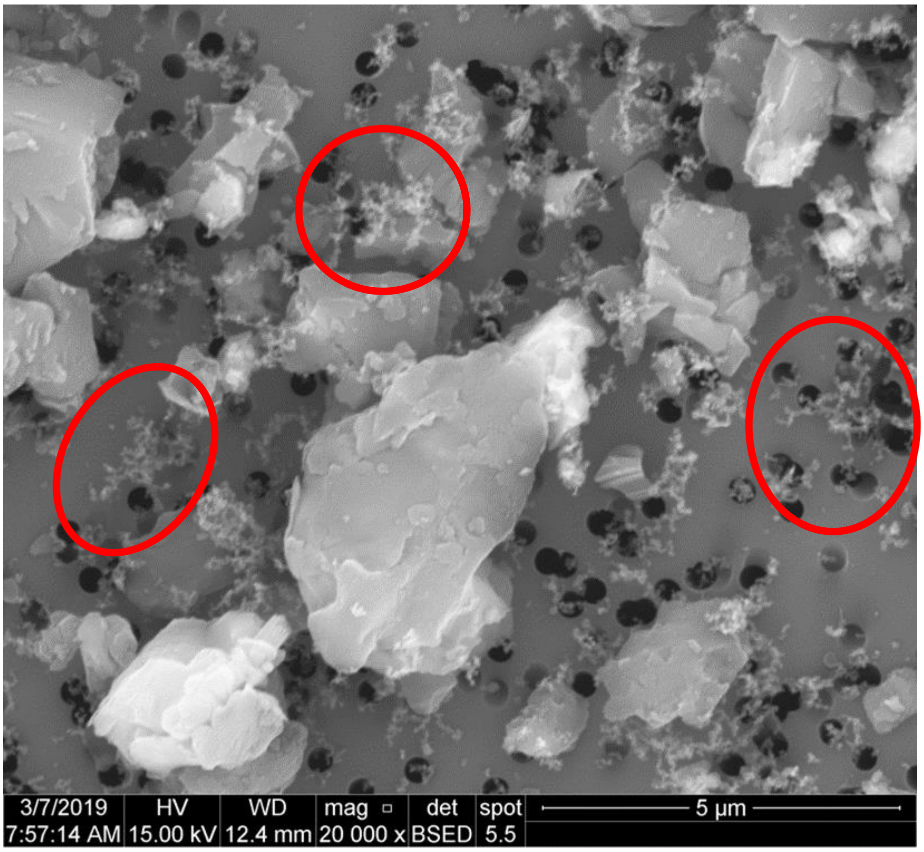


Figure 7 depicts the types of particles composing diesel particulate matter including the elemental carbon core, adsorbed hydrocarbons, liquid condensed hydrocarbon aerosols and sulphates.

This shows agglomerated diesel particulates on filter collected from a Queensland underground coal mine. The scale bar in the bottom right shows 5 microns. The solid black dots are the 0.4-micron pores in the filter. Some of the agglomerated diesel particles that are larger than 1 micron are circled in red [2].

There is a possibility that agglomerated diesel of this size may not be picked up by the current exposure sampling methodology which uses a cascade impactor with a cut-off of 1 micron.

Figure 8: Microscopic image of diesel found on a respirable filter from a Queensland Coal Mine [2].



7.3 What are the health effects/consequences of exposure?

The health effects may vary based on the concentration, frequency, and duration of exposure.

- Short term exposure to high concentrations of DPM can cause headache, dizziness, and irritation of the eye, nose and throat severe enough to distract or disable miners and other workers [3]. There are frequently no symptoms of ingestion, but nausea and vomiting are possible. DPM can be considered a dermal irritant as it may cause drying and cracking due to dissolution of dermal lipids in the skin, rashes or superficial burns [4].
- Prolonged DPM exposure can increase the risk of cardiovascular, cardiopulmonary and respiratory disease (including asthma) and lung cancer [5].

7.4 Who is exposed? And how are they exposed?

There is potential for exposure to DPM for a large cross section of workers across the resources industries. This may affect many of the inspectorate groups within RSHQ including coal mines, mineral mines and quarries, petroleum and gas and explosives. Potential exposure locations of concern include:

- Underground coal mines
- Underground metalliferous mines
- Poorly ventilated diesel workshops in coal mines, metalliferous mines, or quarries

- Drilling rigs using diesel power
- Anywhere the diesel generators or other diesel equipment are used

Note: most concentrations in mining are not high enough for acute effects through skin or ingestion. The most important risk is through inhalation.

7.5 What are the current QLD regulatory requirements for the management of the hazard?

There is **no prescribed regulatory limit** for the management of DPM in the Queensland resources sector. For metalliferous mines QGN21 provides guidance on Management of Diesel Engine Exhaust in Metalliferous Mines [6].

For coal mines **Recommendations** were made in Mines Safety Bulletin No 127 [7], published 24 December 2012 to:

- Adopt 0.1 mg/m³ 8-hr TWA as the exposure limit for DPM, measured as sub-micron elemental carbon (EC) as per New South Wales Machine Design Guideline (MDG) 29 [8]. This standard was set based on the levels adopted by overseas regulatory authorities.
- Adjust the exposure limit for DPM to account for extended shift lengths or non-standard rosters, using an appropriate adjustment model selected by a suitably qualified person [7].

7.6 Current exposure standards and how it's measured

The 0.1 mg/m^3 limit on DPM (measured as sub-micron Elemental Carbon) is based on preventing irritant health effects which are more acute exposures, not protecting against chronic exposures such as the risk of lung cancer. IARC's declaration linking diesel exhaust exposure to lung cancer is likely to result in this limit being reviewed. [7] The NIOSH 5040 method is commonly used to calculate Elemental Carbon [9].

DPM Exposure monitoring uses a respirable cyclone elutriator with a cascade impactor to capture only the submicron fraction, which is assumed to be DPM. These particles do not have much mass, so the sub-micron elemental carbon is measured through combustion. It is possible for agglomerated diesel particles larger than 1 micron to be rejected by the cascade impactor and sub-micron coal dust may be included in the sample.

Recent research has looked at biological markers as indications of diesel exposure including urinalysis [10]. Biological monitoring is a better indicator of what the person has absorbed, as opposed to what they have been exposed to. In addition to being more definitive of exposure, biological monitoring would also be less prone to error than exposure monitoring. Exposure monitoring results may vary based on if the person has worn the monitor correctly for the entire shift and if the exposure over that shift is indicative of their normal exposure.

DPM exposure monitoring data is currently only collected by the RSHQ for the underground coal mines. Data analysis was performed on the RSHQ Personal Diesel results database including 10,589 samples collected between 2002 and 2020. This analysis can be found in Appendix E. The Longwall moves, outbye supplies, development production, return and stone drivage SEGs were found to have average exposures over half the workplace exposure standards (WES). The lognormal 95% upper confidence limit for the longwall moves SEG is above 0.1 mg/m^3, however the geometric standard deviation is 3.5 which indicates a high degree of variability between the tasks in the SEGs. This may be due to intermittent use of diesel-powered longwall shield haulers and road maintenance equipment. As longwall cutting height is getting taller shields are getting heavier and as face widths increase more shields are required. This results in an increased need for diesel powered road maintenance such as graders and LHDs in the shield moving process which is contributing to the diesel exhaust present.

Monitoring should also be done for the underground metalliferous mines. There is potential for the exposures to be higher in the underground metalliferous sector as all the equipment tends to be diesel powered and there is normally a smaller quantity of air flowing through metalliferous mines as there is no requirement of dilution of gases such as methane.

7.7 Trends in other jurisdictions

Table 4: **Workplace Exposure Standards for Diesel Engine Emissions in Various** Jurisdictions shows the exposure standards for various jurisdictions for diesel emissions. These are all measured as Elemental carbon except for the United States, which uses total carbon. Most jurisdictions have set an 8-hour TWA, but very few have set a STEL for DPM.

Table 4: Workplace Exposure Standards for Diesel Engine Emissions in Various Jurisdictions

Country	Diesel Particulate Matter as Elemental Carbon 8-hour Limit (mg/m^3)	Diesel Particulate Matter as Elemental Carbon Short Term Exposure Limit (mg/m^3)
Austria- Underground mining	0.3	1.2
Austria- All others	0.1	0.4
European Union	0.05	No STEL
Germany	0.05	No STEL
Latvia	0.05	No STEL
New Zealand	0.1	No STEL
Sweden	0.05	No STEL
USA MSHA- Metal/Non-metal	0.16 (Total Carbon)	No STEL
New South Wales	0.1	No STEL
Western Australia	0.1	No STEL
Queensland	0.1*	No STEL

*Recommended limit

New South Wales and Western Australia have regulatory limits for DPM rather than recommended levels. Western Australia implemented this limit on 4 December 2020. The 0.1 mg/m^3 limit was first enforced in NSW in February 2021 following a 12-month transition period.

NSW has published a review of their Targeted Assessment program on Diesel Exhaust Emission in Underground Coal Mines [11]. In February 2021, NSW has also published a Position Paper on the Implementation of an Exposure Standard for Diesel Particulate Matter in NSW Mines. This paper cites the AIOH recommended limit of 0.1 mg/m^3 , and considers this achievable with acceptable conventional means to reduce the risk of occupational illnesses to mine workers[12].

7.7.1 Guidance documents on DPM in mining

Several guidance documents on diesel particulate matter are available from other jurisdictions both domestically and overseas.

Australian documents:

- AIOH Exposure Standards Committee, Diesel Particulate matter and Occupational Health issues [13]
- AS/NZS 3584.3 2012, Diesel engine systems for underground coal mines, Part 3: Maintenance [14]
- AS/NZS 1715 2009 Selection, use and maintenance of respiratory protective equipment [15]
- MDG 29 Guideline for the management of diesel engine pollutants in underground environments, April 2008 [8]

Documents produced overseas that are the referenced authority:

- NIOSH RI9687 Diesel aerosols and gases in underground mines: Guide to exposure assessment and control [1]
- OSHA-MSHA Hazard Alert on Diesel Exhaust/ Diesel Particulate Matter [5]

7.8 Recommendations

Diesel particulate matter was declared a group 1 carcinogen by IARC in 2012, when IARC found sufficient evidence linking exposure to diesel exhaust to increased risk of lung cancer. Instead of a recommended limit, RSHQ should specify an Occupational Exposure limit be set for DPM. NSW specifies a limit of 0.1 mg/m^3 (measured as sub-micron elemental carbon).

A standard shift adjustment methodology should be set to calculate exceedances. Upon review of the data, it was noted that reductions factors are inconsistently applied between mines and consultants. The review found that several mines applied reduction factors to samples taken in some months and not others.

Monitoring of diesel exposures should also be performed for underground metalliferous mines and should be centrally collected by RSHQ. Biological monitoring is preferred to personal atmospheric monitoring.

7.9 References

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General hazardous chemicals

8. General hazardous chemicals

8.1 Overview

Summary of the health effects presented by the risk
The potential health effects will depend upon the chemical involved. The examples below illustrate a range of harm from death, through to respiratory disease, neurological diseases, and skin disease.
What we know about the risk (available data and evidence from RSHQ and other sources)
Data was not provided by RSHQ that could help to identify potential general hazardous chemicals and evaluate the level of risk. RSHQ has released two safety bulletins dealing with Xanthates. These documents report cases of incidents causing nausea, vomiting, dizziness, and burns, as well as explosions. There are several significant incident reports from the Department of Mines, Industry Regulation and Safety, Resource Regulator, WA that describe hazardous chemical incidents especially due to the unexpected release of dangerous liquids. The granularity of the Workers' Compensation data did not permit identification of any chemical related diseases. Companies using hazardous chemicals are required to manage them in accordance with hazardous chemical regulation, Recognised Standard 17 for coal mines and QGL03 for metal mines and quarries.
How we can learn more about the impact of this risk in the resources sector in Queensland
It is recommended that targeted assessments of individual location usage of particular hazardous chemicals be undertaken to ensure compliance with regulation. Access to mine biological monitoring and personal exposure monitoring data should be sought.

There are a number of general chemicals that could pose a health hazard. These include gases such as:

- Ammonia and Hydrogen Cyanide
- Refrigerants (freons, hydrocarbons and ammonia)
- Inorganic Acids
- Inorganic Alkalis
- Xanthates
- Surfactants
- Fumigants such as Methyl Bromide

8.2 What is the health hazard?

These compounds by their nature can pose a threat through inhalation, ingestion, and absorption through the skin and other exposed surfaces such as eyes.

8.3 What are the health effects/consequences of exposure?

A detailed description of the potential health effects for a wide range of chemicals can be found in the ILO guide to Encyclopedia of Occupational Health and Safety Chapter 104—Guide to Chemicals (ILO, 2021) or the NIOSH Pocket Guide to Chemical Hazards (NIOSH, 2021). These documents highlight that there are many different exposure routes, other than the primary pathways, that can cause harm, not just breathing in an aerosol.

Table 5: Health effects of some commonly encountered hazardous chemicals

Chemical group	Health hazard
Ammonia	Ammonia is used to manufacture ammonium nitrate—for explosives and fertilizer. As Ammonium Hydroxide it is a common cleaning agent. It is also used as a refrigerant. Industrial poisoning is usually acute, while chronic poisoning, although possible, is less common. The irritant effect of ammonia is felt especially in the upper respiratory tract, and in large concentrations it affects the central nervous system, causing spasms. Irritation of the upper respiratory tract occurs at concentrations of above 100 mg/m^3, while the maximum tolerable concentration in 1 hour is between 210 and 350 mg/m^3. Splashes of ammonia water into the eyes are particularly dangerous. The rapid penetration of ammonia into the ocular tissue may result in perforation of the cornea and even in death of the eyeball.
Hydrogen Cyanide	Sodium and Potassium cyanides can be used in the processing of gold ores. Hydrogen Cyanide may be liberated during this process and also if the salts are allowed to react with acid. Cyanide compounds are toxic to the extent that they release the cyanide ion. Acute exposure can cause death by asphyxia, as the result of exposure to lethal concentrations of hydrogen cyanide (HCN) whether by inhalation, ingestion, or percutaneous absorption; in the last case, however, the dose required is higher. Chronic exposure to cyanides at levels too low to produce such serious symptoms may cause a variety of problems. Dermatitis, often accompanied by itching, an erythematous rash, and papules, has been a problem for workers in the electroplating industry. Severe irritation of the nose may lead to obstruction, bleeding, sloughs and, in some cases, perforation of the septum. Among fumigators, mild cyanide poisoning has been recognized as the cause of symptoms of oxygen starvation, headache, rapid heart rate, and nausea, all of which were completely reversed when the exposure ceased.
Refrigerants (NIOSH, 2021)	Symptoms of mild to moderate refrigerant (freon) poisoning may include: ► Headache ► Irritation of eyes, ears, and throat ► Dizziness ► Frostbite if exposed to quickly expanding gas or liquid coolant ► Vomiting ► Chemical burn on the skin ► Nausea ► Coughing Severe refrigerant poisoning can cause symptoms, including: ► Vomiting blood ► Breathing difficulties ► Loss of consciousness ► Bleeding or fluid build-up in the lungs ► Seizure ► Feeling of the food pipe burning ► Irregular heartbeat ► Confusion

Chemical group	Health hazard
	► Coma or sudden death Some hydrocarbons are used as refrigerants—see VOCs chapter for health effects. Ammonia may also be used industrially.
Inorganic Acids	The inorganic acids (such as hydrochloric acid, nitric acid, and sulphuric acid) are corrosive, especially in high concentrations; they will destroy body tissue and cause chemical burns when in contact with the skin and mucous membranes. In particular, the danger of eye accidents is pronounced. Inorganic acid vapours or mists are respiratory tract and mucous membrane irritants, although the degree of irritation depends to a large degree on the concentration; discolouration or erosion of the teeth may also occur in exposed workers. Repeated skin contact may lead to dermatitis. Accidental ingestion of concentrated inorganic acids will result in severe irritation of the throat and stomach, and destruction of the tissue of internal organs, perhaps with fatal outcome, when immediate remedial action is not taken. Certain inorganic acids may also act as systemic poisons.
Inorganic Alkalis	Potassium hydroxide and sodium hydroxide. These compounds are very dangerous to the eyes, both in liquid and solid form. As strong alkalis, they destroy tissues and cause severe chemical burns. Inhalation of dusts or mists of these materials can cause serious injury to the entire respiratory tract, and ingestion can severely injure the digestive system. Even though they are not flammable and will not support combustion, much heat is evolved when the solid material is dissolved in water. Therefore, cold water must be used for this purpose; otherwise, the solution may boil and splatter corrosive liquid over a wide area.
Xanthates	Refer to Mine Safety Bulletin 171—RSHQ 04 April 2018 Xanthates are used in the processing of some ores. Hazards from xanthates include but are not limited to: ► Production of toxic/flammable decomposition products (carbon disulphide and potentially, alcohol vapours) ► Spontaneous combustion (self-heating in air) that creates toxic combustion products (sulphur dioxide, carbon monoxide and carbon dioxide) ► Acute harm if ingested or absorbed in significant amounts through skin ► Acute irritation if inhaled or absorbed through skin In addition, animal studies indicate xanthates are linked to chronic damage to the liver and neurological system after long-term elevated exposure.
Surfactants	Depending on the chemical formulation, skin and eye irritation is not uncommon (HERA, 2021)
Fumigants such as Methyl Bromide	Methyl Bromide is a controlled substance, and it can only be used as a fumigant for quarantine and pre-shipment purposes. It is a neurotoxic gas and can cause headaches, dizziness, vomiting, nausea, tremors, slurred speech and irritation to the eyes, respiratory system, and skin. Exposure to high concentrations may cause pulmonary oedema and death (Safe Work Australia, 2021c) NIOSH have certified Methyl Bromide as a carcinogen with no safe exposure level (OSHA, 2021b)

8.4 Who is exposed? And how are they exposed?

Persons most at risk to these chemicals are predominantly involved in processing ores, working in laboratories, or undertaking cleaning and maintenance.

Fumigants may be encountered when inspecting or unpacking shipments from overseas. It may be absorbed through the skin or inhaled.

8.5 What are the current QLD regulatory requirements for the management of the hazard?

Part 7 of the CMSHR 2017 and the MQSHR 2017 describes Hazardous Chemicals and dangerous goods. The subdivisions and sections describe:

- The meaning of hazardous chemical and dangerous goods
- The need for the Site Senior Executive (SSE) to maintain a register of hazardous chemicals and dangerous goods
- The requirements for manufacturers, suppliers, and importers to mark and label substances
- The need for the SSE to ensure that hazardous chemicals and dangerous goods are correctly marked and labelled
- The SSE must ensure that a hazardous chemical or dangerous good selected for use at the mine does not create an unacceptable level of risk to a person when used, handled, or stored under standard work instructions
- The SSE must ensure that the mine has standard work instructions (SWI) for using, handling, or storing hazardous chemicals or dangerous goods
- The risk at a mine relating to the handling or storing of a hazardous chemical or dangerous goods must be managed
- The SSE must ensure that appropriate monitoring in relation to a hazardous chemical or dangerous goods is carried out as part of any SWI or other procedure that applies to monitoring
- The SSE must ensure that the mine has a SWI for dealing with leaks and spills
- The SSE must ensure that the mine disposes of hazardous chemicals or dangerous goods appropriately

Exposure to hazardous chemicals that cause or have the potential to cause a significant adverse effect on the safety or health of a person is classified as a high potential incident (HPI) under CMSHR 2017 Schedule 1C and MQSHR 2017 Schedule 1. No HPIs have been reported in the data supplied by RSHQ relating to these chemicals.

Division 3 and subsidiary sections of the MQSHR 2017 outline the requirements for health surveillance for the non-coal mining sector. Health surveillance is required if the SSE reasonably believes or ought to reasonably believe that exposure to a hazard at the mine may cause or result in an adverse health effect under the worker's work conditions and either there exists a valid technique capable of detecting signs of the health effect, or a valid biological monitoring procedure is available to detect the changes from the current accepted values for the hazard. S139 describes the requirements to remove any affected worker from the work environment. S140 describes the use of PPE to manage the exposure if a mine cannot prevent or reduce the exposure by other means.

Subdivision 3 of Division 2 of the CMSHR 2017 describes the requirements for the Coal Mine Workers' Medical Health Surveillance scheme, which includes similar requirements to the above. S 49 specifically requires that the mines Safety and Health Management System must provide for periodic monitoring of the level of risk from hazards at the mine from hazards that are likely to create an unacceptable level of risk. It also requires the employer to ensure that the workers' exposure to the hazard is periodically monitored to assess the level of risk to the worker if the worker is exposed to a hazard at a coal mine that may increase the level of risk. CMSHR -1 Health assessment form lists under question 1.5 Specific coal mine worker position requirements or hazard exposures section (c) Coal mine worker may potentially be exposed to a list of specific hazardous chemicals including:

- Oils, greases
- Solvents
- Phenols
- Isocyanates
- Acids
- Alkalis
- Cement, grout, stone dust
- Detergent, hand cleaners

The medical examination includes assessment of the skin.

Schedule 1C lists a number of notifiable diseases mainly relating to respiratory issues but also including cancers (Schedule 1 in the CMSHR 2017). Schedule 5 refers to general exposure limits for hazards deferring to the National Occupational Health and Safety Commission (NOHSC, 1985-2005) document—Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995). Note this document has been superseded by the Safe Work Australia Workplace Exposure Standards for Airborne Contaminants, last issued 2019 (presently undergoing review).

Recognised Standard 17 Recognised Standard for Hazardous Chemicals under the CMSHA 1999 is a comprehensive document aimed at assisting coal mines in managing the risks associated with hazardous chemicals. Its contents include:

- Classification and labelling of workplace hazardous chemicals
- Manifests and placarding of hazardous chemicals and dangerous goods
- Preparation of safety data sheets (SDS) for hazardous chemicals
    - The content of the SDS including
        - Hazard identification
        - Composition and information on ingredients
        - First aid measures

- Firefighting measures
- Accidental release measures
- Handling and storage
- Exposure controls and personal protection
  - Exposure control measures
  - Biological monitoring
  - PPE
- Physical and chemical properties
- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information

QGL03—Guideline for Hazardous Chemicals (July 2019) issued by the then Department of Natural Resources, Mines and Energy outlines the processes for safe acquisition, storage and use of hazardous chemicals in general under the MQHSA 1999. This mirrors RS-19. The controls required depend upon the specifications outlined in the safety data sheets (SDS) supplied for the hazardous chemical. It is therefore vital that the SDS are accurate and comprehensive enough to permit effective management of the risk. Chapter 11 of the guideline outlines these requirements. It lists more than 120 groups of substances or families, that should be used to ensure consistent labelling of hazardous chemicals.

Exposure to hazardous chemicals not on mine sites is managed under the Work Health and Safety Regulation 2011 for non-mine sites. Schedule 14 of this regulation outlines the requirements for health monitoring (Division 6, sections 368 to 378) for a range of chemicals

Health monitoring requirements may include:

- Demographic, medical and work history
- Records of personal exposure
- Physical examination with emphasis on areas where chemical has impact e.g. respiratory system, peripheral nervous system, or skin
- Urinary/blood analysis

Form 28 Hazardous chemical health report outlines the reporting requirements for any person being assessed for potential adverse health effects due to hazardous chemicals. This form must be sent to WHSQ.

In 2013 WHSQ issued a code of practice for managing the risks associated with hazardous chemicals in the workplace. This document aligns with the Safe Work Australia code of practice described below (WHSQ, 2013).

8.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Safe Work Australia have issued a code of practice for managing the risks of hazardous chemicals (Safe Work Australia, 2020). This is a more comprehensive document than RS-19 and QLG-03 in that it details the overall risk management process (identification, assessment, control identification, monitoring and review, emergency preparedness) as well as the technical components that make up management process. Each section is referenced back to the relevant model WHS regulation.

More details on the management of hazardous chemicals can be found on the Safe Work website: https://www.safeworkaustralia.gov.au/chemicals, including guidance on health monitoring. The health monitoring requirements echo those in the CMSHR 2017 and MQSHR 2017. It includes a list under the Model WHS Regulations of restricted use chemicals. Appendix E outlines the requirements for health monitoring under the model WHSR for specific chemicals, including those where biological monitoring is recommended including:

- Carbon Disulphide
- Dichloromethane
- Butanone (MEK)
- Fluorides

The NSW Workplace Safety and Health (Mines and Petroleum Sites) Regulation 14 requires the development and implementation of an Airborne Contaminants Principal Hazard Management Plan (PHMP) for any chemical or biological contaminant likely to be in the air which include hazardous chemicals. Section 1.3.4 details the requirements for Health Monitoring. Xanthates are listed among the list of common airborne contaminants. It provides a table which identifies potential airborne contaminants associated with specific mining and mineral processing activities. The NSW Resource Regulator published a guide on how to prepare the PHMP and the required elements of the PHMP (RR, 2018).

To assist the development of the PHMP the Resource Regulator has published an information document describing atmospheric contaminants that may exist at worksites, the possible health effects and assistance in risk ranking the hazards. All chemicals used, handled, or stored in a workplace in excess of set allowances under schedule 11 of the NSW WHSR (2017) are notifiable to the Resource Regulator. Schedule 14 of the WSHR (2017) outlines the requirements for health monitoring for specific chemicals.

In WA Hazardous substance control is outlined in division 3 of part 7 of the Mine Safety and Inspection Regulation (MSIR, 1995). A "suitable" assessment should be carried out for each hazardous substance, if a significant risk of exposure is identified then a report must be prepared outlining how the risk will be controlled, this may include exposure monitoring and personal health surveillance monitoring.

WHSQ has issued a guideline for health monitoring of potential exposure to methyl bromide (WSHQ, 2015). The type of health surveillance required includes medical examination with emphasis on the nervous and respiratory systems and skin. Blood bromide levels should be monitored post-shift at the end of work week.

8.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

Table 6: Current exposure standards for common hazardous chemicals

Chemical	Safe Work Australia	Proposed Safe Work Australia	OSHA		NIOSH		ACGIH	
	TWA	TWA	TWA	STEL	TWA	STEL	TWA	STEL
Carbon Disulphide	10 ppmv	10 ppmv	20 ppmv ceiling		1 ppmv	10 ppmv	1 ppmv	
Ammonia	25 ppmv	20 ppmv	50 ppmv		25 ppmv	35 ppmv	25 ppmv	35 ppmv
Hydrogen Cyanide	10 ppmv peak	1 ppmv	10 ppmv		4.7 ppmv		4.7 ppmv	
Hydrochloric Acid	5 ppmv	2 ppmv	5 ppmv		5 ppmv		5 ppmv	
Nitric Acid	2 ppmv	2 ppmv	2 ppmv		2 ppmv	4 ppmv	2 ppmv	4 ppmv
Sulphuric Acid	1 ppmv 3 ppmv STEL	0.1 ppmv	1 mg/³		0.1 mg/m³		0.2 mg/m³	
Sodium Hydroxide	2 mg/m³	2 mg/m³	2 mg/m³		2 mg/m³		2 mg/m³	
Potassium Hydroxide	2 mg/m³	2 mg/m³	Repealed		2 mg/m³		2 mg/m³	
Methyl Bromide	5 ppmv	1 ppmv	20 ppmv ceiling		Carcino-gen reduce to lowest feasible concentration		1 ppmv	

Note Freons are not included in the above table as there are a large number of compounds in this family, the TWA range from 2 to 1000 ppmv depending on the compound.

Similarly, it is not possible to cite exposure standards for surfactants.

Carbon Disulphide appears to be the only compound listed relevant to this chapter with a Biological Exposure Index of 0.5 mg/gm creatinine in urine (Safe Work Australia, 2021b).

Where Safe Work Australia have proposed a reduced exposure standard this is in response to a review of the available literature on the epidemiology including submissions from the AIOH and accessing the ACGIH, NIOSH and HSE, indicating that the current exposure standard is not adequate to manage the risk.

WHSQ recommend a blood bromide BOEL of 12 mg/L. They also recommend urinary bromide determination though there is currently no recognised BOEL (WHSQ, 2015).

8.8 How is the hazard measured/evaluated in the workplace?

8.8.1 Current method and its limitations

There are no Australian Standards for these chemicals.

NIOSH methods:

- Ammonia–6016–Ammonia by impaction then ion chromatographic analysis
- Hydrochloric Acid–7907 - Volatile acids impaction then ion chromatographic analysis
- Hydrogen Cyanide–6010–Hydrogen Cyanide
- Sodium Hydroxide–7405 - Alkali Metal Cations
- Potassium Hydroxide–7405 -Alkali Metal Cations
- Sulphuric Acid–7908–Non-volatile acids
- Nitric Acid–7907 - Volatile acids impaction then ion chromatographic analysis
- CF2ClCCL2F–1020(2)–Solid sorbent tube GC
- CCl2F2–1018(2) - Solid sorbent tube GC

OSHA methods:

- Nitric Acid - ID-165SG–Acid Mist
- Sulphuric Acid - ID-165SG–Acid Mist
- Ammonia–ID-188–Ammonia–solid sorbent
- Methyl Bromide–ID-1680–Methyl Bromide–solid sorbent GC/FID

ISO- 21438 parts 1 to 3 (2007 to 2010) Workplace Air- Determination of Inorganic Acids by Ion Chromatogram.

The problem with these techniques is that they require collection of a sample into a trapping medium, safe storage of the sample, transport back to a laboratory and the analysis in that laboratory. Errors can creep in at any of these stages. In addition, as the techniques are not evaluated in real time, inevitably there is a delay between identification of any excessive exposure, controlling the emission, prevention of repeat exposure and treatment of the individual if necessary.

There are a wide variety of screening techniques and research-based techniques that have been used for monitoring these chemicals, such as the Drager stain tubes.

8.8.2 Emerging technology/research

As with other chemicals there are range of techniques that are being developed including:

- Wearable passive badges for acids and alkalis (Negi et al 2011)

- Real time monitoring for HCN and NH3 using electrochemical sensors, chemiluminescence or semiconductors (Oizom, 2021, or Airmet, 2021)

These techniques are still regarded as advisory at this stage rather than being able to be used for compliance monitoring. Similarly, indicator or stain tubes can be used for investigative and indicative purposes.

8.9 What health monitoring data is currently available to RSHQ? (for each industry sector)

8.9.1 What is the status of the data/issues with the data?

No health monitoring data relating to exposure to these chemicals was provided by RSHQ. The workers' compensation data did not provide enough detail to identify the causes of many diseases. However, there were a number of cases of contact dermatitis (15), other diseases of the skin (9), asthma (2), bronchitis (36), other respiratory diseases (12) as well as unspecified diseases (5) that may be linked to exposure to these chemicals.

RSHQ has issued two safety bulletins relating to the safe use of Xanthates in Mining (no. 132 27 March 2013 and no. 171 04 April 2018). They point out that Xanthates are liable to self-heat and combust as well as posing health hazards relating to liver and the neurological system. Xanthates readily decompose to produce carbon disulphide. They react with water, heat causes decomposition, mixing with acidic chemicals, generating toxic plumes containing carbon disulphide.

8.9.2 What does it tell us about workers exposures?

This information does not provide any real insight into the potential exposure of workers to other chemicals.

8.9.3 How could data collection and management be improved?

Interrogation of the workers' compensation data in more detail to identify the causes of the diseases outlined above would better indicate which chemicals are causing problems if any.

Targeted assessment programs looking at the management of individual hazardous chemicals at selected worksites could investigate what information workplaces have on the risk of exposure to particular hazardous chemicals. Consideration should be given to increased biological monitoring.

8.10 What other exposure data is available/in peer reviewed literature?

8.10.1 Historical data

Safe Work Australia published a National Hazard Exposure Worker Surveillance (NHEWS) in 2012, which was a national survey aimed at examining the nature and extent of Australian workers dermal exposure to selected occupational disease-causing hazards. The main findings were that:

- 37 % of worker responses indicated that they had been exposed to skin contact with chemicals at work in the week preceding the survey. The chemicals involved included: Detergents, Organic Solvents, bases, and alkalis (Safe Work Australia, 2012).
- Mining workers reported the second highest number of hours per week (4.5) to chemicals—though this may be due to a small sample, mainly due to organic solvents, with lower exposure to bases and alkalis, paints etc, and non-bituminous fuels.

Mine Safety Alert 196 (22 May 2008) reports a mine worker suffering chemical burns to eyes due to high pressure fluid release (a mixture of sulphuric acid, phenol, and phenol sulphonic acid). Immediate treatment by paramedics prevented any serious harm.

The Health Risk Assessment (HRA) of an open cut coal mine in 2017 provided by RSHQ identifies under hazardous materials including oils, greases, and degreasers particularly for maintenance personnel, paint, and solvents again for maintenance personnel. These compounds are covered in other chapters of this report. None of the chemicals discussed in this chapter were noted as being used on site.

RSHQ provided a copy of a 2017 HRA of an open cut coal mine. Several potential health hazards were identified including refined hydrocarbons (oils and greases etc) and volatile organic compounds (such as acetone, acetic acid, naphtha, diethylene glycol and white mineral oil. None of the chemicals discussed in this chapter were listed as potential hazards.

A Health Risk Assessment carried out in 2017 at a gold mine identified potential issues with the storage and use of chemical in the mill laboratory but did not specify what these chemicals were. Ammonia and Cyanide were identified as being produced in the gold room. It was noted that the smell of ammonia was overpowering during the inspection causing respiratory discomfort. Real time monitoring for ammonia in the gold room was recommended. The mill operators and mill superintendent were identified as having a level 4 Health hazard rating (out of 10) leading to an overall moderate risk ranking, due to the limited exposure of the workers to these chemicals. No personal exposure monitoring of these workers to these chemicals was recommended.

There are a number of significant incident reports and safety bulletins from the Department of Mines, Industry Regulation and Safety, Resource Regulator, WA including:

- SIR 256—unexpected release of sulphuric acid slurry—minor injuries including burns (DMIRS, 2017).
- SIR 233—unexpected release of hot 95 % caustic solution—thermal and caustic burns to workers face and body (DMIRS, 2015b).
- SIR 228—hose rupture causing release of anhydrous ammonia at -33 ° C—worker received serious chemical burns requiring hospital treatment (DMIRS, 2015a).
- SIR 177—sudden release of air conditioning system hydrocarbon gas causing fire and explosion—worker received minor burns to chest and arms (DMIRS, 2012).
- SIR 165—sudden depressurisation of an ANFO charge- up kettle—Operator received facial and eye injuries (DMIRS, 2010).
- Dangerous Goods SIR 01-19—Ammonia release during ship unloading—Five workers were exposed requiring medical examination (DMIRS, 2018).
- Dangerous Goods Safety Bulletin No. 0320—Safe storage of ammonium nitrate—warning of hazard of fire generated decomposition and toxic gas emissions (DMIRS, 2020).
- Dangerous Goods Safety Bulletin no. 116 and Mine Safety Bulletin 130—Gold-leaching reagent containing cyanide—incorrect labelling and transportation by supplier suggested that the reagent did not contain any cyanide (DMIRS, 2016).

- Dangerous Good Safety Bulletin no. 114—Flammable refrigerants in non-refillable cylinders—Reports of non-refillable cylinders being used to import flammable refrigerants. There is a danger that if the burst disc opens it will not reseal which could result in the total loss of the flammable gas—It is illegal for vendors to transport or supply flammable refrigerants in these cylinder (DMIRS, 2014)

8.10.2 Current data

An HRA in 2019, commissioned by the Petroleum and Gas Inspectorate, of a workover rig and hybrid coil drilling operation, considered hazardous chemicals mainly inorganic compound including caustic soda. A number of activities were observed that increased the risk of worker exposure, including applying chemicals to hot surfaces which increased the volatilisation of the chemical, and decanting liquids into smaller unlabelled containers. The qualitative risk assessment ranked the potential exposure as low risk except for the derrickman where the risk was significant.

An HRA carried out in 2020 commissioned by the Petroleum and Gas inspectorate of a biogas power generation facility noted the use of oils and degreasers.

A similar HRA carried out at a second biogas power generation facility and sewerage treatment plan, identified four 210 l drums of unknown chemical, that may have been engine coolant. No other comments were made on potential hazardous chemicals.

As mentioned above RSHQ has released two safety bulletins dealing with Xanthates. These documents report cases of incidents causing nausea, vomiting, dizziness, and burns, as well as explosions.

In the 2020 Workplace Health and Safety Queensland report on key work health and safety statistics, there were a total of 375 serious claims for chemical and other substances (WHSQ, 2021).

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Hand-Arm Vibration (HAV)

9. Hand-Arm Vibration (HAV)

9.1 Overview

Summary of the health effects presented by the risk
Hand-arm vibration (HAV) is a form of vibration (oscillatory motion) that is transmitted from hand-held tools or hand-operated machinery to a worker's hand and arm. Vibration from hand-held power tools is typically in the higher frequencies (e.g., 40–300 Hz). Examples of hand-held tools that present a risk include grinders, needle guns, impact wrenches, air drills and chipping hammers. Exposure can result in hand-arm vibration syndrome (HAVS) and vibration white finger (VWF). However, in warmer climates, workers exposed to HAV are more likely to experience the neurological impacts (e.g., tingling and numbness) rather than vascular affects such as VWF.
What we know about the risk (available data and evidence from RSHQ and other sources)
► There is very little published peer reviewed data on the exposure of workers to HAV in tropical and subtropical climates ► The occurrence of HAVS is believed to be underreported in tropical/sub-tropical countries such as Australia [1]. There is minimal data available for the assessment of risk to workers in the mining and resource sectors in Queensland ► The HAV exposure data provided by RSHQ is minimal and consists of no quantitative and scant qualitative data ► The data consists of some LTI reports and workers' compensation claims combined with minimal qualitative information ► The data was of little value in evaluating the magnitude and variability in exposures in the Queensland resources sector to HAV and the hazard is likely to be underestimated
How we can learn more about the impact of this risk in the resources sector in Queensland
► It is recommended that organisations within the Queensland resources sector be encouraged to include HAV exposures in their health risk assessments ► It is recommended that workers regularly using hand-held or hand-operated tools (e.g., rattle guns, air chisels, needle guns, impact wrenches, grinders, rock drills, and chipping or scaling hammers) have their exposures quantitively assessed and that they be reviewed for symptoms of HAVS with a focus on neurological impacts such as tingling and numbness

9.2 What is the health hazard?

The health hazard is exposure to hand-arm vibration, defined as:

> *"the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders."* [2]

9.3 What are the consequences of exposure?

Repeated, prolonged exposure to HAV causes damage to the soft tissues of the hand and arm. Resulting conditions such as Raynaud's Phenomenon, known as vibration white finger (VWF), and carpel tunnel syndrome have been well documented in the literature [3, 4]. Along with other musculoskeletal and neurological disorders, these conditions are collectively referred to as *'hand-arm vibration syndrome'* (HAVS) [3]. HAVS symptoms include numbness and tingling in the fingers, pain, aches, stiffness, loss of grip strength, sensitivity, and manual dexterity [5]. Exposure can progress to VWF (a state of abnormally increased vasoconstriction) [6]. However, there is good evidence to suggest that the vascular (e.g., VWF) and neurological effects of HAV develop and progress independently of each other [7].

The clinical features of HAVS in tropical countries (warm climates) differ from the features of the syndrome in temperate countries (cooler temperatures) [1]. Current research has reported that a combination of cooler temperatures and HAV is required for the development of VWF, HAV alone does not result in VWF in warmer climates [8]. However, neurological symptoms associated with HAVS such as finger tingling and numbness are observed in tropical and sub-tropical climates [1].

The latency period for HAVS ranges from less than 12-months to 10 years, depending on individual factors and the exposure scenario [9]. Neurosensory injuries are reported to occur with a 3-time factor shorter latency period than Raynaud's phenomenon (VWF), at equal HAV exposures [10].

Workers exposed to HAV have an approximately 4-5-fold increased risk of vascular and neurological diseases compared to non-exposed workers [10]. Like other health hazards, the development of adverse health effects from exposure to HAV is based on a dose response relationship (i.e., severity of injury increases in proportion to the number of hours of exposure and the intensity and frequency of exposures) as well as environmental and individual factors [4]. Individual and non-occupational factors can include a history of smoking, previous hand injury, diabetes mellitus, arthritis, and non-occupational exposures to HAV [11].

Although the mechanism is not well understood, there is a known relationship between VWF and an increased incidence of noise induced hearing loss (NIHL) [12]. Some research suggests that there may also be a connection between HAV exposure and NIHL however the possibility of a synergistic effect is still being debated [13].

In a recent Australian study conducted in a Queensland Aluminium Refinery, 82% of the 522 employees surveyed reported using powered hand tools and 66% of these workers reported experiencing HAVS-like symptoms such as white finger (4%), tingling (48%), numbness (26%), numbness and tingling (25%) and muscle and joint concerns of the neck and upper limbs without numbness and tingling (6%) [14].

A study conducted in a sub-tropical area of China involving assessment of HAV exposure received by workers using grinders with hand-held workpieces, found that the average exposure dose was measured as A(8) was 5.3 ± 2.0 m/s^2 [15]. The researchers found a positive association between the vibration exposure duration and the occurrence of finger blanching, finger numbness and finger coldness [15]. With 15.4% of grinder operators experiencing finger blanching and 27.5% finger numbness [15].

Who is exposed? And how are they exposed?

A range of roles and tasks involve the use of hand-held or hand-operated powered tools and machinery that may expose operators to HAV. In the mining and quarrying, and petroleum and gas sectors examples include:

- Workshop personnel and tyre fitters that use electrically/ pneumatically powered tools such as rattle guns, air chisels, needle guns, impact wrenches, and grinders
- Boilermakers that use grinders and other powered hand-held tools
- Use of chainsaws, push mowers, hand-held saws for concrete, metal, and other materials
- Use of rock drills and chipping or scaling hammers and air-leg rock drills

A South African study reported the prevalence of HAVS in gold miners as 15% with a mean latency period of 5.6 years and all cases of HAVS were associated with a history of exposure to rock drills [16].

Table 7: Examples of HAV values for common hand-held tools [17]

Tool	Vibration Level (m/s^2)	Time to Action Level	Time to Guidance Limit	Estimated Daily Exposure Time	Average Daily Exposure Level (m/s^2)
Angle grinder metal plate	2.5	8.5 hr	>24 hr	4 hr	1.7
Jack hammer on asphalt	9.9	30 min	2 hr	1 hr	3.5
Rattle gun	13.7	16 min	1 hr	1 hr	4.8
Rattle gun on track	19.9	8 min	30 min	1 hr	7
Needle gun on track	17.9	9 min	37 min	1 hr	6.3
Engraver	6.2	1.5 hr	5 hr	30 min	1.6

Source: [17]

- The 2008 Australian *National Hazard Exposure Worker Surveillance* survey found that of the workers surveyed, 24% reported exposure to vibration and of these, 43% reported exposure to HAV [4]
- A recent phone survey of the Australian working population (Australian Workplace Exposure Study) estimated that on any one day about 3.8% of the Australian working population are exposed to HAV over the daily exposure action limit (2.5 m/s^2) and 0.8% over the limit (5.0 m/s^2)
- Workers who were males, who had a trade or apprenticeship qualification and were working in remote areas, were more likely to be exposed [6]

9.4 Current QLD regulatory requirements for HAV management

9.4.1 Coal mining

There is no specific mention of vibration in the Coal Mining Safety and Health legislation. However, there is the general obligation to develop and implement a safety and health management system and to ensure that risk to persons from coal mining operations is at an acceptable level. These general obligations would apply to all health hazards, including HAV.

9.4.2 Metalliferous mines and quarries

The only mention of vibration in the Mining and Quarrying legislation is in section 11 of the Regulation, which refers to a requirement for the site senior executive to ensure a record of monitoring carried out under section 9(2) is made and kept for 30 years, including for vibration monitoring.

9.4.3 Petroleum and gas

The *QLD Petroleum and Gas (Production and Safety) Act 2004*, Chapter 9 Safety, does not specifically deal with the management of vibration exposures related to Operating Plant. In some cases, the *QLD Work Health and Safety Regulation 2011*, Chapter 4, Part 4.2 Hazardous Manual Tasks, would apply. Part 4.2 requires the PCBU to manage the risk of hazardous manual tasks and mentions vibration as a possible risk factor for musculoskeletal disorders.

9.4.4 Explosives

There is no specific mention of hand-arm vibration in either the *QLD Explosives Act 1999* or *QLD Explosives Regulation 2017*. Management of the risks associated with this hazard related to the use of explosives would be governed under the relevant health and safety related legislation for the site.

9.5 Exposure standards for HAV

In Australia, there are currently no regulatory limits for HAV. Although there are no set limits, Safe Work Australia has published some guidance materials as follows:

- Hand-arm vibration information sheet
- Guide to measuring and assessing workplace exposure to hand-arm vibration
- Guide to managing risks of exposure to hand-arm vibration in workplaces

There is also some mention of vibration in the Safe Work Australia model Work Health and Safety Regulations within clause 60(2)(a). Vibration is listed as a possible contributor to a hazardous manual task that may contribute to musculoskeletal disorders [18]. Some of the model codes of practice also mention vibration, including the *"Code of Practice for Managing and Preventing Hearing Loss at Work"* [19].

Standards Australia has published standards for the measurement and evaluation of vibration including:

- *"AS ISO 5349.1:2013 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration; Part 1 General requirements[20]"* and
- *"AS ISO 5349.2:2013 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration; Part 2 Practical guidance for measurement at the workplace"[21]*

But as stated above, there are no established Australian workplace exposure limits for HAV, only guidance on its evaluation and management. However, Europe agreed in 2002 on the European Union Directive 2002/44/EC, which requires employers to control exposures and introduce health surveillance if vibration levels exceed a set 'action value' and to immediately reduce exposure exceeding the maximum 'exposure limit'. These values are summarised in Table 8 below and are referenced in the Safe Work Australia Guide to measuring and assessing workplace exposure to hand-arm vibration. Agreement on the directive requires member countries to enact the limits within local legislation, for example in the UK there is a specific regulation for vibration *"The Control of Vibration at Work Regulation 2005"*.

Table 8: European Directive Exposure Values for Hand-Arm Vibration

Average daily vibration exposure A(8) (1)	Hand-arm vibration
Exposure action value	2.5 m/s^2
Exposure limit value	5 m/s^2
(1) Standardised to eight-hour energy equivalent frequency weighted acceleration magnitude	

Source:[22].

In the US, the ACGIH has established non-regulatory limits for vibration within their document *"Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices"*. The values established are consistent with those set by the EU Directive.

9.5.1 Comparison of standards for HAV

In April 2013, Standards Australia replaced the previous Australian Standard for HAV (AS 2763:1998) with two standards adopted from ISO (AS ISO 5349.1:2013 and AS ISO 5349.2:2013). In these standards, HAV is evaluated based on the "vibration total value" (VTV). Measurements of the VTV have values that are greater than measurements on a single axis of up to 1.7 times (typically between 1.2 and 1.5 times) the magnitude of the greatest component. The daily vibration exposure is based on the 8-hour energy equivalent acceleration value "A(8)". This was previously 4 hours.

HAV evaluation involves the measurement of vibration magnitude at the grip zones or handles coupled with exposure time. Additional factors such as grip forces, postures of the hand and arm, the direction of vibration and environmental conditions are not considered in the calculation but should be observed and recorded. The Australian Standards (adopted ISO standards) do not set exposure limits but do provide guidance on evaluation. Therefore, the limits set by other authorities would be required as an occupational exposure limit (OEL) such as the limits set by the European Union Directive 2002/44/EC (see Table 2 above).

In terms of an OEL for HAV, the EU Directive is well matched to the Australian Standard (adopted ISO standard) as it quotes an action value and exposure limit in m/s^2, which is standardised to an eight-hour energy equivalent frequency weighted acceleration magnitude (A(8)) and combines all three orthogonal axes (a_{hwx}, a_{hwy}, a_{hwz}) into one value (VTV). The British regulation has adopted the EU Directive and is also therefore based on an 8-hour equivalent value.

It is recommended that the Australian adopted ISO standard (AS ISO 5349.1:2013) be used for the measurement and evaluation of HAV and that VTV values be compared with the EU Directive or an appropriate internal company standard. But it should also be recognised that the dose-response curve in the ISO 3549.1 standard was developed based on the occurrence of VWF and is used as the basis for the threshold limit values for HAV exposure [1]. Because VWF is far more common in association with cold climates and develops separately from the neurological effects that are more common in warmer climates, the current version of the ISO 5349.1 should be applied with caution to exposures in warm countries like Australia [1].

9.6 Measurement and evaluation of the hazard

Vibration measurements should be performed on randomly selected exposed workers in accordance with the procedures established in the Australian Standards (*AS ISO 5349.1:2013 and AS ISO 5349.2:2013)*. For measurements of HAV the instrument used must conform to *"ISO 8041:2005 Human response to vibration – Measuring instrumentation"*. The instrument must be checked for correct operation before and after use, and calibration must be traceable to a recognised standard maintained by an accredited laboratory. The worker being measured wears an accelerometer (transducers) on their hand gripping the tool and the device will typically measure the vibration transmitted to the hand through the three axes (x, y and z) simultaneously. The measurement instrument applies a weighting and displays the results on screen. The formulae used to calculate the A(8) value is as follows:

$a_{hv} = \sqrt{(a^2_{hwx} + a^2_{hwy} + a^2_{hwz})}$ and then $a_{hv(eq,8h)} = A(8) = a_{hv}\sqrt{T/T_0}$

Where: T is the daily duration of exposure to vibrations with magnitude a_{hv} and T_0 is the reference duration of 8hrs.

9.7 Summary of health monitoring data currently available to RSHQ

9.7.1 Data provided

- Lost Time Injury Data
- Accepted workers' compensation claims
- Health Risk Assessments for individual sites

9.7.2 LTI data

There were six (6) reported lost time injuries that may potentially be related to HAV exposure over the period 2011 to 2020. The injuries were all from opencut coal mining. Injuries included:

- Repetitive strain injury to wrist/s x2
- Carpel tunnel syndrome x2
- Pins and needles and numbness in right hand over time
- Experienced pain in wrists over a period of time

9.7.3 Workers' compensation data

The accepted workers' compensation claims data for the resources sector for the period 2016/2017 to the incomplete year of 2020/2021 includes one (1) specified claim for exposure to HAV from the use of pneumatic tools. However, there were additional claims that may be related to HAV, including:

- 8 claims for diseases of the musculoskeletal system related to use of pneumatic tools, 7 of which were from underground copper ore mining, and 1 in opencut coal mining
- 43 claims for carpel tunnel syndrome (some of which may be related to HAV exposures), including:
  - 13 in opencut coal mining
  - 9 in opencut bauxite mining
  - 6 in underground coal mining
  - 4 in underground copper ore mining
  - 3 in drilling and boring support services
  - 2 in other construction material mining
  - 2 in oil and gas extraction
  - 1 in explosives manufacturing
  - 1 in other mining support services
  - 1 in gravel and sand quarrying
  - 1 in mineral exploration services

9.7.4 Health Risk Assessments (HRAs)

The Health Risk Assessments provided included reviews completed for specific sites, including coal mines (3 reports), metalliferous mines (1 report), and petroleum and gas drill rig sites (6 reports). Vibration was briefly listed as an occupational health hazard in most of the HRAs, but the focus tended to be on whole-body vibration only with minimal mention of HAV. None of the reports included any specific quantitative data on HAV exposures. The HRAs from the mining and quarrying sectors listed the following groups as potentially exposed to HAV:

- Workshop personnel and tyre fitters that use electrically/ pneumatically powered tools such as rattle guns, air chisels, needle guns, impact wrenches, and grinders
- Boilermakers that use grinders and other powered hand-held tools

9.8 Status of the data available to RSHQ

The HAV exposure data provided by RSHQ consists of LTI reports and workers' compensation claims combined with some qualitative information. More data is required to be able to evaluate the magnitude and variability in exposures in the Queensland resources sector to HAV, and the hazard is presently likely to be underestimated.

9.8.1 How could data collection and management be improved?

It is recommended that organisations within the Queensland resources sector be encouraged to include HAV exposures in their health risk assessments. Workers regularly using hand-held or hand-operated tools (e.g., rattle guns, air chisels, needle guns, impact wrenches, grinders, rock drills, and chipping or scaling hammers) should have their exposures quantitively assessed and that they be reviewed for symptoms of HAVS with a focus on neurological impacts such as tingling and numbness.

9.9 References

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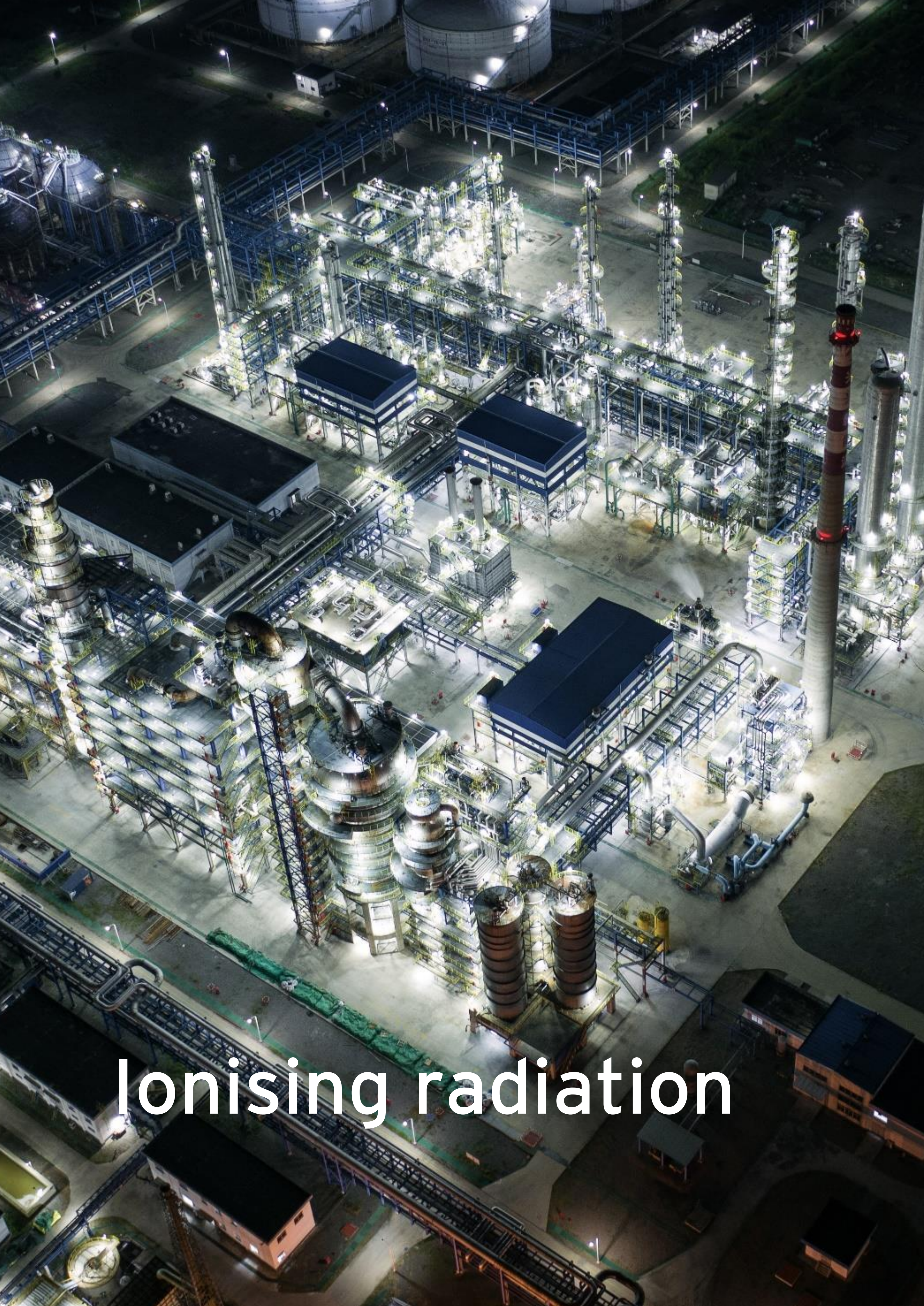

Ionising radiation

10. Ionising radiation

10.1 Overview

Summary of the health effects presented by the risk
There are two types of health effects from exposure to ionising radiation (IR)—deterministic and stochastic effects. Deterministic effects occur with a known dose threshold and include acute radiation syndrome, skin burns, loss of hair, sterility, and death. Stochastic effects involve damage to the genetic material in cells, which may result in radiation-induced cancers, or in heritable disease in descendants of the exposed person [1]. For both cancer and heritable effects, the probability of the occurrence, but not the severity, depends on the dose [1]. The risk of stochastic effects increases with dose but there is no threshold [1]. Health effects from acute high to moderate IR exposures are well studied and understood. However, the scientific evidence for health impacts from low dose or low-dose rate IR (low radiation delivered over a long period of time) is more limited and the subject of ongoing scientific debate [2]. Effects can include leukemia, solid and partially solid cancers, and some limited evidence of tissue effects, including cardiovascular disease and cataracts.
What we know about the risk (available data and evidence from RSHQ and other sources)
The ionising radiation exposure data provided by RSHQ is minimal and consists of scant qualitative data and no quantitative data. The data consists of brief mentions of potential exposures to man-made sources such as from wireline logging systems in both the mining and petroleum and gas sectors. The data was of little value in evaluating the magnitude and variability in exposures in the Queensland resources sector to ionising radiation from both man-made and natural sources. There are some relevant data on exposures in the Australian resources sector including data reported by the Australian Mineral Sands Industry for 2000 to 2008, which shows average exposures for workers in dry separation plants ranges from 1.3 to 3.1 mSv per year and mining operator exposures were <0.1mSv/year [3]. Up to 10 mSv/year is considered to be a very low dose with no observed or expected health effects (typical background exposure range) [3]. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) also manages the Australian National Radiation Dose Register (ANRDR), which produce summary reports on exposures including within the uranium mining industry and more recently the mineral sands mining industry. A 2019 review of the register showed that exposures in the mineral sands mining industry from 2016-2018 were low with the average effective dose being <0.2mSv/year and the maximum doses being <0.8mSv/year [4].
How we can learn more about the impact of this risk in the resources sector in Queensland
Comprehensive guidance and requirements for the management of IR is provided by ARPANSA, it is recommended that RSHQ ensure references, within legislation and guides, to ARPANSA documents are kept up to date and that health monitoring information is reviewed.

10.2 What is the health hazard?

The hazard is exposure to a source of ionising radiation. Radiation is a form of energy travelling either as electromagnetic waves or high-speed particles. Radiation is termed 'ionising' if it has sufficient energy to remove an electron from an atom of a molecule as it passes through matter. Ionising radiation includes gamma and X-rays travelling as electromagnetic waves, and alpha or beta travelling as high-speed particles. Non-ionising radiation does not have sufficient energy to ionise and is covered separately in its own topic.

Sources of ionising radiation in the resource sector include man-made (e.g., ash analysers, density meters, X-ray devices, and metal detectors) and naturally occurring radioactive material (NORM) (e.g., uranium).

Every day the general population is exposed to natural background ionising radiation present in our environment. Sources include terrestrial radiation in rocks and soil, radon gas, IR in food, and cosmic radiation [2]. The exposure levels depend on geographical location, including altitude and type of soil and rock present, as well as a person's diet [2]. People may also be exposed to IR from medical diagnostic tests and treatments (e.g., X-rays). On average, Australians are exposed to 1.5 mSv per year from natural sources, however the range of radiation exposure is highly variable [2]. This average Australian exposure level (1.5 mSv) is about the same amount of radiation received from 75 chest X-rays [2].

10.3 What are the consequences of exposure?

The adverse effects from IR arise from the energy deposited in the tissue by the radiation [2]. Different types of ionising radiation (i.e. gamma rays, x-rays, and alpha or beta particles) have different patterns of release and penetrating power [2]. There is no difference in the health effects from exposure to natural sources of IR compared with man-made sources. Therefore, direct comparisons can be made between natural and man-made sources of exposure in terms of potential adverse health impacts [2].

Acute High-Dose Ionising Radiation Health Effects

The adverse health effects of acute high to moderate dose exposures are well known and have been studied since the discovery of X-rays at the end of the 19^{th} century [5]. The main source of this information is the Life Span Cohort study of Japanese survivors of the atomic bombings [6]. There are two types of health effects from IR exposure—deterministic and stochastic effects.

Deterministic effects occur in the short term and are caused by extensive cell death or cell malfunctioning [5]. When deterministic effects occur at a high enough rate they can impair the integrity and compromise the function of organs and tissues [1]. Examples of deterministic effects include acute radiation syndrome, skin burns, loss of hair, and sterility [5]. Acute radiation syndrome is an illness caused by irradiation of the whole or a significant portion of the body and requires a large dose of penetrating radiation delivered over a short period of time [7]. The symptoms follow a reasonably predictable course and are related to cellular deficiencies and the reactions of various cells, tissues, and organ systems to the IR dose [7]. The severity of deterministic effects increases with the dose and a threshold dose is needed for damage to occur [1]. High enough acute exposures can result in death (above 1 000 to 10 000 mSv) [2].

Stochastic effects involve damage to the genetic material in cells, which may result in radiation-induced cancers, or in heritable disease in descendants of the exposed person [1]. For both outcomes (cancer and heritable effects), the probability of the occurrence, but not the severity, depends on the dose [1]. The risk of stochastic effects increases with dose but there is no threshold [1].

Chronic Low-Dose Ionising Radiation Health Effects

In comparison to the well-studied acute effects of high to moderate IR exposures, the scientific evidence for health impacts from low dose or low-dose rate IR (low radiation delivered over a long period of time) is more limited and the subject of ongoing scientific debate[2]. Possible health effects from low dose-rate IR exposure reported in the literature from epidemiological research include:

- Slight increased risk of leukemia [8]
- Increased risk of solid cancers (e.g., cancers of the lung, brain and central nervous system, liver, stomach, colorectum, kidney, bladder and prostate [9]
- Increased risk of partial solid cancers [9, 10]

Apart from cancer risk, there is growing evidence of other potential health effects such as cardiovascular disease and cataracts. Normally, non-cancer diseases are classified as deterministic tissue reactions, which are characterised by a threshold dose [11]. Current international consensus, which forms the basis of the radiation protection standards, states that below an absorbed dose of 100 mGy, no clinically relevant tissue damage occurs [11]. However, recent epidemiological findings indicate that an excess risk of non-cancer diseases occurs following exposure to lower doses of IR than was previously thought [11]. The evidence is the strongest for cardiovascular disease (CVD) and cataracts [11].

10.4 Who is exposed? And how are they exposed?

Workers in the Queensland mining industry could be exposed to ionising radiation from man-made sources or from naturally occurring radioactive material (NORM).

According to *QGL 1 Guideline for management of Naturally Occurring Radioactive Material (NORM) in metalliferous mines* - the two principal types of ionising radiation generated by NORM at mines are:

- Alpha particles (in dust and radon)
- Gamma (high energy electromagnetic rays) radiation

The hazards associated with alpha radiation are inhalation and ingestion of the particles. Some known routes of exposure to alpha radiation include:

- Inhalation of airborne dust containing NORM
- Inhalation of radon emanating from ore surfaces, for example core, drill cuttings broken ore stockpiles or underground drives or from groundwater entering or collecting in underground drives
- Inhalation of fume containing radioactive components such as polonium in copper smelting operations
- Ingestion of radionuclides, for example via dust on skin transferred to the mouth while eating
- Absorption through skin of liquids or inhalation of airborne mists of pregnant solvent or solutions containing NORM

The hazard for gamma radiation is from whole body exposure to sources, commonly referred to as 'gamma shine'. These sources of gamma radiation include:

- Tailings dams
- Ore bodies
- Drill cores and other samples
- Ore stockpiles
- Radium scale deposits

Health Risk Assessments (HRAs) identified potential exposure to Ionising radiation as part of bore/well casing and logging services (wire line) and are principally gamma ray sources.

The following information was provided within sample HRAs for the P&G sector (please note that there was no information about how often this type of work is completed, or any way to determine potential exposure rates from the HRA): "*In wireline logging systems, the drill string is first removed from the well and the logging string (a series of logging tools connected together) is then lowered to the bottom of the well on a cable (the wireline) that carries the measurement data signals back to the surface where they are recorded on a log. As the wireline tool is slowly raised, the log plots the parameter being measured against the depth.*

The gamma and neutron sources used in these tools are normally transported in separate heavy containers. The containers in which radiation sources are transported, moved and stored are generally designed to provide adequate shielding and radiation safety under most climatic conditions."

10.5 Current regulatory requirements for radiation exposure management

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) publish the following range of document categories within the Radiation Protection Series:

- *Fundamentals*— ARPANSA's 'Fundamentals' set the core principles and are written in an explanatory and non-regulatory style[12]
- *Codes*—The 'Codes' are regulatory in style and may be referenced by regulations or conditions of licence[12]
- *Guides*— The 'Guides' provide recommendations and guidance on how to comply with the Codes or apply the principles of the Fundamentals[12]

To the extent possible the publications give effect in Australia to international standards and guidance from sources such as the International Commission on Radiological Protection (ICRP), the International Commission on Non-Ionising Radiation Protection (ICNIRP), the International Atomic Energy Agency (IAEA), and the World Health Organisation (WHO)[12].

The following ARPANSA Fundamentals, Codes and Guides may apply within the resources sector to the management of radiation:

- *RPS F-1 Fundamentals for Protection Against Ionising Radiation 2014**
- *RPS C-1 Code for Radiation Protection in Planned Exposure Situations 2016**
- *RPS G-2 Guide for radiation Protection in Existing Exposure Situations 2017**
- *RPS C-2 Code for the Safe Transport of Radioactive Material 2019*
- *RPS C-4 Code of Radiation Protection Requirements for Industrial Radiography 2018*
- *RPS No. 5 Code of Practice and Safety Guide for Portable Density/Moisture Gauges Containing Radioactive Sources 2004*
- *RPS No. 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005*
- *RPS 9.1 Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing 2011*
- *RPS No. 11 Code of Practice for the Security of Radioactive Sources 2019*
- *RPS No. 13 Code of Practice and Safety Guide for Safe Use of Fixed Radiation Gauges 2007*
- *RPS No. 15 Safety Guide for the Management of Naturally Occurring Radioactive Material (NORM) 2008*

It is important to note that the documents marked with an asterisk (*) above replace the superseded document currently referenced by the *QLD Mining and Quarrying Safety Health Regulation 2017* - RPS No. 1: National Standard for Limiting Occupational Exposure to Ionising Radiation [NOHSC:1013(1995)].

Sealed radioactive sources are regulated by Queensland Health under the *Radiation Safety Act 1999* and *Radiation Safety Regulation 2010*. Licences are required for the possession, transport and use of radiation sources. A radiation safety and protection plan and radiation safety officer are required along with set standards of practice.

Mining

Naturally occurring radioactive minerals being mined or processed on mining leases or land the subject of mineral development licences or exploration permits are regulated under the *Coal Mining Safety and Health Act 1999* and the *Mining and Quarrying Safety and Health Act 1999*. However, once the minerals are no longer within the boundaries of land the subject of a mining lease, mineral development licence or exploration permit within the definitions of the *Mineral Resources Act 1989*, they are regulated by the *Radiation Safety Act 1999*.

Under the *Coal Mining Safety and Health Act 1999* and the *Mining and Quarrying Safety and Health Act 1999,* the site senior executive has an obligation to develop and implement a safety and health management system, ensuring that the site controls risk to an acceptable level. This system must address the scenario of a person in a mine's workings or local environment being exposed to ionising radiation, at above dose limits, from a naturally occurring radioactive mineral at the mine.

The *Mining and Quarrying Safety and Health Regulation 2017* specifically covers ionising radiation as follows:

- Section 69(2)(a): The site senior executive must ensure that, before explosives are used, a risk management process is carried out to identify the hazards that may arise or interact from the use of explosives including radiation.

- Section 145: If a person could be exposed to radiation above acceptable limits, the site senior executive must ensure the mine has a system to provide for the safety management of the radiation and that the system is complied with.

The following guides and notices are relevant to the management of potential exposures to ionising radiation in Queensland mining:

- Guidance Note QGN12 Radiation protection from naturally occurring radioactive materials (NORM) during exploration

- Guideline QGL1 Guideline for management of Naturally Occurring Radioactive Material (NORM) in metalliferous mines

- Guidance Note QGN10 Handling explosives in surface mines and quarries

- Guidance Note QGN11 Handling explosives in underground mines

QGN12 and QGL1 provide specific guidance for the risk management of potential exposures to NORM within exploration activities and in metalliferous mines. Both guides are based on the requirements of the ARPANSA Code (*RPS No. 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005*). These documents require the following key actions:

- An **assessment of risk** of exposure to NORM. According to the Code of Practice, the activity concentration of 1 Bq/g is currently the internationally accepted level for defining the scope of regulation for naturally occurring materials containing uranium and thorium. At activity concentrations less than 1 Bq/g, these minerals would be considered inherently safe. At higher activity concentrations, the site shall be assessed on a case-by-case basis and the activities may also be determined as being inherently safe, e.g., if the source of the radionuclides is insoluble or immobile. Where it is likely that the potential dose may exceed the member of the general public dose limit, a comprehensive risk assessment should be carried out and controls be implemented according to the level of risk

- Development of a **radiation management plan**

- Development of **radiation waste management plan,** where required

- Consideration of the need for Site **Radiation Safety Officer**

- Implementation and management of required **control measures** including dust suppression and extraction, ventilation, enclosed operator cabins, maintenance, separation of workers from NORM, shielding and sealing surfaces, work procedures and practices, education and training, and PPE

- **Monitoring workers' exposures**

- **Record management**

Petroleum and Gas

The QLD *Petroleum and Gas (Production and Safety) Act 2004*, Chapter 9 Safety, does not specifically deal with the management of radiation exposures related to Operating Plant.

The following guides and notices are relevant to the management of potential exposures to ionising and non-ionising radiation in P&G sites:

- Petroleum and gas safety alert no.65 29 October 2014 Radioactive substances and apparatus.

Explosives

There is no specific mention of radiation in either the *QLD Explosives Act 1999* or *QLD Explosives Regulation 2017*. Management of the risks associated with this hazard related to the use of explosives would be governed under the relevant health and safety related legislation for the site.

10.6 Exposure standards for radiation

Ionising Radiation Exposure Standards

The dose limits for persons occupationally exposed to ionising radiation are set out in *RPS C-1 Code for Radiation Protection in Planned Exposure Situations (Rev. 1) (2020)*, Schedule A and are as follows [13]:

Table 9: Dose limits for persons occupationally exposed to ionising radiation

Type of limit	Limit (18 years and over)[1]	Limit (more than 16 years but under 18 years)[1,5]
Effective dose	20 mSv per year, averaged over a period of five consecutive years[2]	6 mSv per year
Annual **equivalent dose** to the lens of the eye	20 mSv per year, averaged over a period of five consecutive years[3]	20 mSv per year
Annual **equivalent dose** to the skin[4]	500 mSv per year	150 mSv per year
Annual **equivalent dose** to the hands and feet	500 mSv per year	150 mSv per year

1. *The limits apply to the sum of the relevant doses from external exposure in the specified period and the 50-year committed dose from intakes in the same period.*
2. *With the further provision that the effective dose must not exceed 50 mSv in any single year. When a pregnancy is declared by an occupationally exposed female, the working conditions of that person should be such as to ensure that the additional dose to the embryo/foetus would not exceed about 1 mSv during the remainder of the pregnancy.*
3. *With the further provision that the equivalent dose must not exceed 50 mSv in any single year.*
4. *The equivalent dose limit for the skin applies to the dose averaged over 1 cm^2 of the most highly irradiated area of the skin. The dose to the skin also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin.*
5. *Persons under the age of 16 years must not be subject to occupational exposure. Persons under the age of 18 but more than 16 years must not be subject to occupational exposure unless they are under supervision and only for the purpose of training for employment or for the purpose of studies in which sources are used.*

As per the *RPS No. 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*, section 3.6.7, for employees not directly involved in work with radiation, a dose constraint should be adopted which would normally be related to the public effective dose limit.

Schedule B of the *RPS C-1 Code for Radiation Protection in Planned Exposure Situations (Rev. 1) (2020)*, sets the following dose limits for members of the public [13]:

Table 10: Dose limits for members of the public

Type of limit	Dose Limit[1]
Effective dose	1 mSv per year[2] (above background)
Annual **equivalent dose** in the lens of the eye	15 mSv per year
Annual **equivalent dose** in the skin[3]	50 mSv per year

1. *The limits apply to the sum of the relevant doses from external exposure in the specified period and the 50-year committed dose (to age 70 years for children) from intakes in the same period.*
2. *In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over five years does not exceed 1 mSv per year.*
3. *The equivalent dose limit for the skin applies to the dose averaged over any 1 cm2 area of skin, regardless of the total area exposed. The dose to the skin also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin.*

Note: Effective dose is defined within the RPS C-1 and is basically *"a measure of dose designed to reflect the amount of radiation detriment likely to result from the dose"*.

10.7 Measurement and evaluation of the hazard

The measurement and evaluation of worker exposures should follow the guidance provided in *RPS 9.1 Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing 2011*.

There are a number of techniques to measure ionising radiation in the workplace. The technique used for monitoring ionising radiation depends on the type of ionising radiation being evaluated and the exposure scenario. The main techniques include:

- Area surveys with direct reading monitor
- Area monitoring with wipe testing
- Assessment of external IR exposure (i.e., passive and active dosimetry)
- Assessment of internal IR exposure (i.e., personal contamination surveys, air monitoring, external monitoring and bioassay) [14]

Monitors can be categorised as follows:

- What they measure—count rate, dose rate, or dose
- The type of detection technology (e.g., gas-filled detectors, scintillation detectors, semiconductors, thermoluminescent detectors [14]

The correct instrument should be chosen based on the IR type and exposure scenario.

10.8 Summary of worker exposure data currently available to RSHQ for ionising radiation

Documents provided that included data related to ionising radiation

The documents provided for this report that included data relevant to ionising radiation consisted of HRAs only. There was no HPI, LTI, or health surveillance data provided by RSHQ as part of the review. Although it is assumed that RSHQ does hold individual occupational exposure results for IR exposures in metalliferous mines, as QGL1 requires these results to be provided to the Mines Inspectorate in an approved form. The Mines Inspectorate also forward these results to ARPANSA for inclusion in the ANRDR. ANRDR was established to enable workers' dose records to be tracked and recorded throughout their career and to make available to workers, summaries of their periodic and cumulative exposures.

Health Risk Assessments (HRAs)

The Health Risk Assessments provided included reviews completed for specific sites, including coal mines (3 reports), metalliferous mines (1 report), and petroleum and gas drill rig sites (6 reports). Ionising radiation was briefly listed as an occupational health hazard in most of the HRAs. None of the reports included any specific quantitative data on ionising radiation exposures.

Status of the data available to RSHQ

The ionising radiation exposure data provided by RSHQ is minimal, consisting of brief mentions of potential exposures to man-made sources such as from wireline logging systems. More data is needed to be able to evaluate the magnitude and variability in exposures in the Queensland resources sector to ionising radiation, and at present the hazard is likely to be underestimated.

10.9 How could data collection and management be improved?

It is recommended that organisations within the Queensland resources sector be encouraged to include the potential for ionising radiation exposures in their health risk assessments, including from man-made sources and NORM.

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Lead

11. Lead

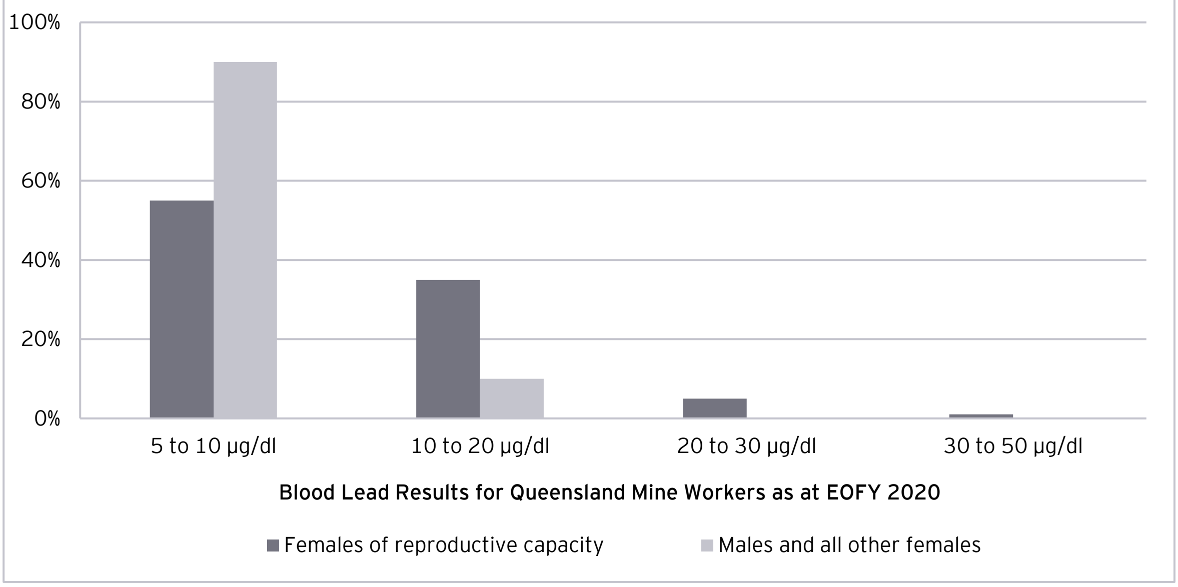
11.1 Overview

Summary of the health effects presented by the risk
Lead is a known cancer-causing agent and reproductive toxin and can affect various other organs and induce changes in behaviour

What we know about the risk (available data and evidence from RSHQ and other sources)

Blood lead data is regularly collected quantifying the exposure of workers. The acceptable exposure levels are currently under review and expected to be reduced substantially. RSHQ does not currently hold any personal airborne exposure data. The 2019-2020 Annual Safety and Health Performance Report figure 1-52 (below) outlines the blood lead levels for Queensland Mine Workers as at EOFY2020.

Figure 9: Figure 1-52 BLL for Queensland Mine Workers as at EOFY 2020



From Q2 2021 RSHQ will apply the following lead risk work blood lead levels:

- 5 µg/dL for females of reproductive age (RSHQ has assumed that females under the age of 50 were classified as reproductive, for the purposes of analysis, as the reports received from Queensland Health did not identify the reproductive status of the females)
- 20 µg/dL for others

The 98th percentile (98 percent less than) were:

- 12.05 µg/dL for females of reproductive capacity
- 24.1 µg/dL for others

How can we learn more about the impact of this risk in the resources sector in Queensland?
At present the data provided by RSHQ does not permit an assessment of the degree of exposure of workers to lead. No information was provided that indicates whether the blood lead data supplied reflects all workers potentially exposed to lead. It is recommended that the representativeness of the data be clarified. It is recommended that organisations within the Queensland resources sector include information about the working areas or their SEG's to allow for identification of higher risk areas and the reproductive status of the workers to enable the identification of exceedances.

11.2 What is the health hazard?

Exposure of workers to lead containing dust or fume—refer to the *Metal Dust and Fume, Including Welding* chapter (chapter 20) for more information about Fume. The lead-containing dust can be inhaled or ingested, and thereby cause the adverse health effects described in the next section.

11.3 What are the health effects/consequences of exposure?

A detailed description of potential health effects can be found in the NHMRC Information paper: Evidence on the effects of Lead on Human Health (NHMRC, 2015). Most adverse health effects are the result of long-term exposure to lead.

Exposure to inorganic lead can cause the following conditions:

- Cancer (Category 1A reproductive toxin and IARC 2A probable Human Carcinogen)
- Increase blood pressure (short term effect)
- Cardiovascular disease
- Kidney damage
- Effects on the nervous system, including difficulty concentrating, hearing loss, loss of balance, tremors
- Behavioural changes like aggression, anxiety, and depression
- Anaemia
- Reduced fertility
- Birth defects including low birth weight and developmental delays in children due to the small bodies and developing brains and nervous systems

11.4 Who is exposed? And how are they exposed?

Workers are principally exposed to lead in dusts or as a fume during the processing of ores or smelting. Inhalation is the main exposure mechanism though care must also be taken to avoid ingesting the dust.

- Miners in the MMQ sector mining lead-containing ore

- Operators processing lead-containing ore
- Operators refining or processing lead-containing ore, including molten lead
- Persons interacting with lead acid batteries
- Persons interacting with paint containing more than 1% lead (lead is no longer used in paint, but it is still widespread in the environment from prior usage)
- Persons grinding, blasting, cutting, buffing or otherwise disturbing surfaces containing lead

11.5 What are the current QLD regulatory requirements for the management of the hazard?

The *Queensland Mining and Quarrying Safety and Health Regulation 2017* (MQSHR 2017) refers to the management of risk of exposure to inorganic lead in a number of sections:

- In section 9 lead is used as an example of risk monitoring through biological monitoring
- In Part 14 (Work Environment) of Subdivision 2 of division 1 of Chapter 2, lead is referred to under the monitoring of the exposure of workers; section 136 and 139 refers to the NOHSC National Standard for the Control of Inorganic Lead at Work [NOHSC:1012]' which has been superseded by Safe Work Australia guidance. This document outlines biological exposure indices for lead as described below
- Section 139 (3) refers to removal of a worker who has blood lead level at or above the worker's removal level (NOHSC section 15(24) and does not resume a lead risk job until the workers' blood lead level is less than the level stated for the worker in the NOSHC inorganic lead standard 1012 section 15(27)
- Division 3 of Chapter 2 refers to health surveillance and subdivision 2 section 145B describes the requirement for health surveillance where the Site Senior Executive (SSE) reasonably believes or ought to reasonably believe that exposure to a hazard at the mine may cause, or result in, an adverse health effect, provided either a valid technique capable of detecting signs of the health effect exists: or a valid biological monitoring procedure is available to detect changes from the current accepted values for the hazard. The example given is for blood lead levels caused by substances containing lead
- Lead is also regarded as a hazardous chemical and is included in the requirements for managing the risk due to hazardous chemicals—see other chemicals chapter for more details

In contrast the *Work Health and Safety Regulation 2011* which applies to workplaces other than mine sites, draws all elements for the management of the risk of exposure to inorganic lead into one section—Part 7.2—Lead in Chapter 7, Hazardous Chemicals. This section has four parts:

- The lead process defines a wide range of activities as being lead processes including:
    - Work that exposes a person to lead dust or lead fumes arising from the manufacture or handling of dry lead compounds
    - Work relating to batteries involving lead
    - Melting, casting, or spraying molten lead or alloys containing more than 5 % by weight of lead metal

  - Recovering lead from its ores, oxides, or other compounds by thermal reduction process
  - Dry machine grinding, discing, buffing, or cutting by power tools alloys containing more than 5 % by weight of lead metal
  - Machine sanding or buffing surfaces coated with paint containing more than 1 % dry weight of lead
  - A process by which electric arc, oxyacetylene, oxy gas, plasma arc, or a flame is applied for welding, cutting, or cleaning, to the surface of metal coated with lead or paint containing more than 1 % dry weight of lead
  - Radiator repairs that may cause exposure to lead dust or lead fumes
  - Fire assays if lead, lead compounds or lead alloy are used
  - Hand grinding and finishing lead or alloys containing more than 50% by dry weight of lead
  - Spray painting with lead paint containing more than 1 % dry weight of lead
  - Melting lead metal or alloys containing more than 50 % by weight of lead metal
  - Using a power tool, including abrasive blasting and high-pressure water jets to remove a surface coated with paint containing more than 1 % dry weight of lead
  - Foundry processes involving the casting of lead alloys (> 1 % of lead metal)
  - A process decided by the regulator to be a lead process under section 393
- Control of risk
  - Containment of lead contamination
  - Cleaning methods
  - Prohibition on eating, drinking, and smoking
  - Provision of changing and washing facilities
  - Laundering, disposal, and removal of personal protective equipment
  - Review of control measures
- Lead risk work—includes blood lead levels in excess of which work is defined as lead risk work
  - If the work meets the criteria for lead risk work, then the regulator must be notified in writing within seven days
- Health monitoring
  - Health monitoring must be in place before the worker first commences lead risk work
  - And 1 month after the worker first commences lead risk work
  - For females not of reproductive capacity and males

- With blood lead level < 30 µg/dL every six months
- With blood lead levels > 30 µg/dL and < 40 µg/dL every 3 months
- With blood lead levels > 40 µg/dL every 6 weeks

- For females of reproductive capacity
  - With blood lead levels < 10 µg/dL every three months
  - With blood lead levels > 10 µg/dL every six weeks

The WHSR 2011 is modelled on the model WHS Regulations issued by Safe Work Australia (see below for details).

11.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Safe Work Australia promotes the model WHS legislation and the management of exposure to lead through Part 7.2—Lead in Chapter 7 Hazardous Chemicals. In addition, the webpage www.safeworkaustralia.gov.au/topic/lead provides an overview with embedded links to all aspects of the management process. Control of exposure focusses on the Person Conducting the Business or Undertaking (PCBU) identifying lead processes or lead risk work. Control is then to be affected through:

- Confinement to a lead process area at the workplace
- These areas are to be kept clean and steps taken to prevent any persons from eating or drinking in the process area
- An eating and drinking area is provided that is free from lead contamination
- Provision and maintenance of changing rooms, and washing, showering and toilet facilities to minimise lead contamination and exposure
- Information about the health risks and toxic effects associated with exposure to lead is provided to workers before they start the lead process
- Steps are taken to minimise the workers' exposure to lead when handing contaminated PPE and ensure that contaminated PPE is disposed of appropriately
- Health monitoring is provided to workers undertaking lead risk work as per the WHSQ regulation above
- A PCBU must ensure that a worker is not exposed to concentrations of airborne chemicals above the workplace exposure standard
- Application of the Code of Practice—Managing risks of hazardous chemicals in the workplace, July 2020. This document outlines the risk management process to be followed stressing the hierarchy of controls well as health monitoring and review

In NSW, lead is included under the Work Health and Safety Regulation 2017, Mining Work Health and Safety (Mines and Petroleum Sites) Regulation 2014, and for hazardous substances, as per the Model WHS legislation described above. The monitoring requirements and controls must be described in the Health Control Plan required under Division 3 Principal Control Plans, in Part 2, Managing Risks, of the Work Health and Safety (Mines) Regulation 2014. The minimum requirements of the Health Control Plan are outlined in Schedule 2 of the Regulation. The Work Health and Safety (Mines and Petroleum Sites) Regulation (2014) allows the Regulator to direct a PCBU to provide health monitoring (section 109 of Part 3).

In WA under the *Mine Safety and Inspection Regulation 1995*, Division 4 outlines the requirements for Health Surveillance monitoring and Part 7 Division 3 outlines the general requirements for the management of exposure to hazardous substances. Control of Atmospheric Contaminants is described in Part 9.12. The exposure standards refer to the "Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment" [NOHSC:1003 (1995)] declared by the NOHSC and published in May 1995. This document has been superseded by the Safe Work Australia *WORKPLACE EXPOSURE STANDARDS FOR AIRBORNE CONTAMINANTS* dated 2019.

11.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

The Queensland Mining and Quarrying Safety and Health Regulation 2017 refers to the National Standard for the Control of Inorganic Lead at Work [NOHSC:1012]' issued in 1994. This health monitoring requirements have been updated by the SafeWork Australia Guide for Health Monitoring of Lead (Inorganic) issued in 19 February 2020.

Monitoring is to be carried out in accordance with AS 3640- 2009 for inhalable dust.

Table 11: Exposure standards for inhalable dust from AS 3640-2009

Organisation	TWA	STEL	Comment
Safe Work Australia (2019)	0.05 mg/m^3		
ACGIH (2020) Lead chromate	0,05 mg/m^3 0.0002 mg/m^3	 0.005 mg/m^3	
Worksafe NZ	0.05 mg/m^3		
OSHA	0.05 mg/m^3		
NIOSH	0.05 mg/m^3		
HSE	0.15 mg.m^3		

The biological monitoring requirements and trigger levels in the NOHSC document—referred to by the MQSHR has been superseded by the 2020 SafeWork Australia Guide for Health Monitoring of Lead (Inorganic) which states:

A worker must be immediately removed from carrying out lead risk work if biological monitoring of the worker shows that the worker's blood lead level is:

- *Greater than or equal to 30 µg/dL (1.44 µmol/L) for females not of reproductive capacity and males, and*
- *Greater than or equal to 10 µg/dL (0.48 µmol/L) for females of reproductive capacity*

The guide goes on to say:

A worker must not return to lead risk work until the worker's blood lead level is:

- *Less than 20 µg/dL (0.97 µmol/L) for females not of reproductive capacity and males, or*
- *Less than 5 µg/dL (0.24 µmol/L) for females of reproductive capacity*

The WA Department of Mines, Industry Regulation and Safety define threshold action blood lead levels for lead risk work as follows in the table below, which correlates well with the Safe Work Australia values above.

For male workers and female workers (not of reproductive capacity):

Table 12: Threshold action blood lead levels for lead risk work – male and female workers not of reproductive capacity

< 10 µg/dL	► Re-test 6 monthly
10–<20	► Counsel worker and review personal hygiene/work practice ► Liaise with employer regarding remedial measures (review personal hygiene workplace exposure and safety controls) ► Re-test at three months
20 - <30	► Counsel worker and review personal hygiene/work practice ► Consider removal from lead work when BLL exceeds 25 µg/dL ► Liaise with employer regarding remedial measures (review personal hygiene workplace exposure and safety controls) ► Re-test at six weeks ► Consider medical examination
>30	► Remove from lead work and notify all parties including WorkSafe without delay ► Conduct medical examination within seven days hygiene/work practice ► Counsel employee and review personal hygiene/work practice ► Liaise with employer regarding remedial measures (review personal hygiene workplace exposure and safety controls) ► Re-test in one month and so forth ► Medical practitioner may certify suitable to return to lead work when BLL is less than 20 µg/dL

For Female workers of reproductive capacity:

Table 13: Threshold action blood lead levels for lead risk work – females of reproductive capacity

< 5 µg/dL	► Re-test 6 monthly
5– <10	► Counsel worker and review personal hygiene/work practice ► Liaise with employer regarding remedial measures (review personal hygiene workplace exposure and safety controls) ► Re-test at six to eight weeks
>10	► Remove from lead work and notify all parties including WorkSafe without delay ► Conduct medical examination within seven days ► Counsel employee and review personal hygiene/work practice ► Liaise with employer regarding remedial measures (review personal hygiene workplace exposure and safety controls) ► Re-test in one month and so forth ► Medical practitioner may certify suitable to return to lead work when BLL is less than 5 µg/dL

11.8 How is the hazard measured/evaluated in the workplace?

11.8.1 Current method and its limitations

Currently industry monitors the potential exposure of workers to inorganic lead via personal exposure monitoring and/or health monitoring via blood lead levels as outlined above.

RSHQ did not supply any personal exposure monitoring data and the blood lead data supplied is analysed below and described against the criteria outlined above.

Blood lead monitoring correlates to the risk to the worker but is not helpful in identifying the source of the lead as it represents integrated exposure over the entire work cycle. Whilst it does monitor the cumulative health risk of the worker, it cannot be used to assess the effectiveness of individual controls.

The data supplied by RSHQ cannot be linked to workplace dust levels.

11.8.2 Emerging technology/research

See below for summary of literature review carried out by AIOH and Safe Work Australia as part of the review of exposure standards.

11.9 What health monitoring data is currently available to RSHQ? (for each industry sector)

11.9.1 What is the status of the data/issues with the data?

The Workers' compensation statistics provided by RSHQ do not provide enough detail to identify any lead-related cases.

The data set provided by RSHQ was analysed as part of this report. These blood lead results were reported based on the RSHQ memorandum of understanding with Queensland Health. The data set contained data from July 2017 to December 2020.

There were no identifiable HPI relating to lead exposure.

There were 37,211 data points contained in the original data set. It was noticed that there were repeats of the data, where the same person ID would have the same exact reading twice or even three times on the same day. It was decided to only include one sample per person per day and there were 1,471 such points found in the data set which were removed from the analysis. This leaves 35,750 discrete points analysed as part of the data set.

- The data set includes the row number, the date of the sample, the person ID, the age of the person, the contaminant, the exposure level, and the gender of the person
- Two ages were adjusted in the data set:
  - "0" was changed to 56 based on the Subject ID's age on the other testing dates
  - 220 was changed to 20 based on the assumption that the 2 key was held down during coding as there were no other samples for this person from which we could extrapolate the correct age
- Two samples in the database with exposure levels listed at "0" were changed to 0.001 for the sake of the analysis

NOTE: As there was no data provided on reproductive capacity, we assumed that all females between the ages of 16 and 50 were of reproductive capacity (consistent with the RSHQ application). Those over the age of 51 were assumed not to be of reproductive capacity for the sake of this analysis. As mentioned above, this would be important information to have for a more meaningful analysis of the data

11.9.2 What does it tell us about workers exposures?

A detailed analysis of the blood lead data supplied by RSHQ is available in Appendix B.

It is difficult to use these data to estimate the exposure of the overall workforce potentially exposed to lead risk work due to the varied sampling frequency of workers defined by the previous blood lead level determination, this will bias the data toward higher values as exceedances mandate quicker repeat testing.

Figure 10: Average Blood Lead Level by Sex for the period 2017 -2020. This illustrates the trends in the blood lead levels by age. An exponential trend line was used to compare the data, which shows a slight decrease in blood lead levels by age. Figure 10 shows the average blood lead levels by quarter for males and females. These parameters remain steady over time.

Figure 10: Average Blood Lead Level by Sex

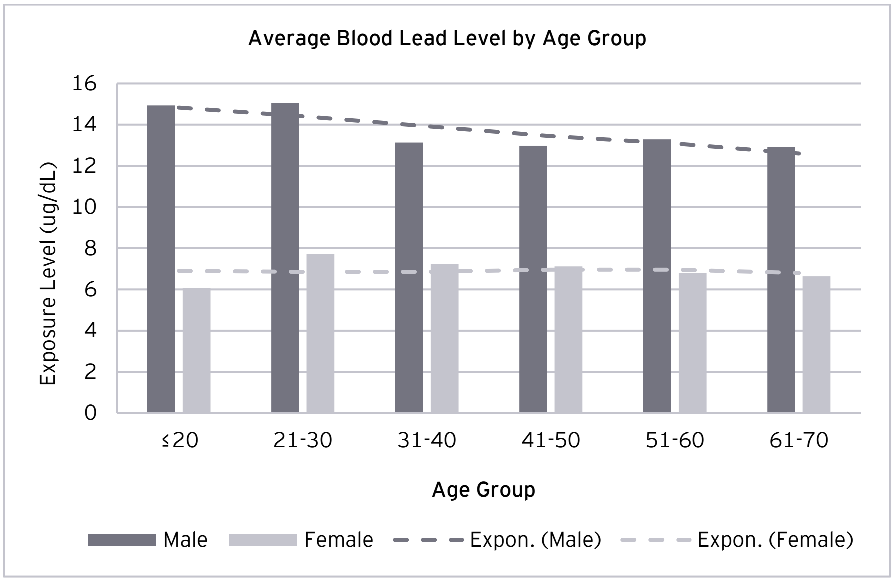
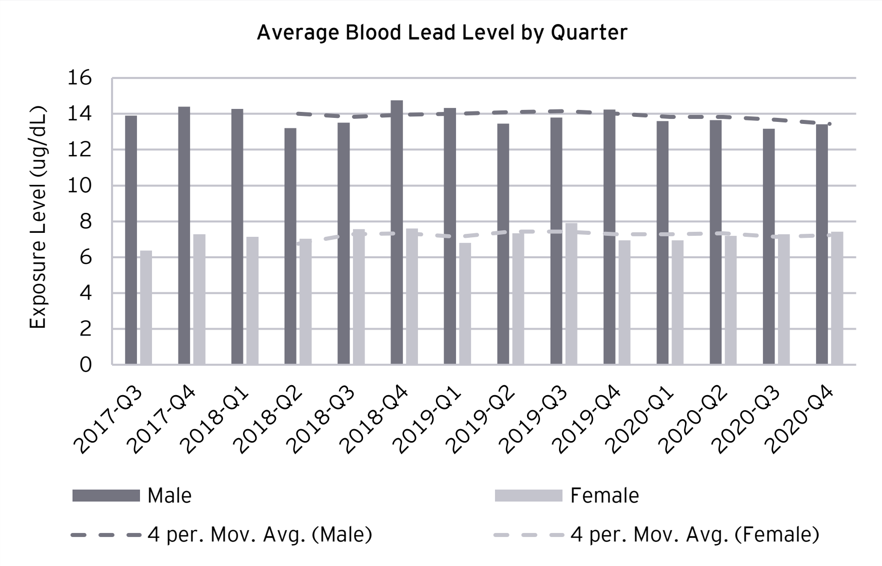


Figure 11: Average Blood Lead Level by Quarter



The highest blood lead level detected was 44.194 µg/dL for a male and 26.115 µg/dL for a female.

Overall, 21 % of samples taken from males and non-reproductive females exceeded the 20 µg/dL lead risk worker level defined by RSHQ and 99.3 % exceeded the 5 µg/dL for reproductive females.

Overall, just under 1 % of samples taken from males and non-reproductive females exceeded the 30 µg/dL Safe Work Australia removal level and 15 % exceeded the 10 µg/dL for reproductive females

The table below shows the Percent exceedances by year for the two categories. It is hard to draw any conclusion in terms of time-based behaviour from these data.

Table 14: Percentage exceedances by year for males and reproductive females

Year	Male and non-reprod Female		Female	
	>20 µg/dL	>30 µg/dL	>5 µg/dL	> 10 µg/dL
2017	24.5	1.0	99.4	11.8
2018	22.1	1.0	99.4	17.0
2019	21.4	1.2	99	16.5
2020	18.6	0.4	99	11.7

These data indicate that females of reproductive capacity are more at risk of excessive lead exposure than others.

11.10 How could data collection and management be improved?

Indication of a worker's reproductive capacity is important in determining the exposure levels for this population and exceedances, as females of a reproductive capacity are much more at risk than others.

There is no data to indicate what industry sector or workgroup (SEG) this person belonged to. The availability of SEG data would make the analysis of this data much more useful in identifying areas of concern for future focus. We recommend that SEG data be included in future data collection.

11.11 What other exposure data is available/in peer reviewed literature?

11.11.1 Historical data

The Department of Mines Industry Safety and Regulation, WA used to collect worker exposure data via the CONTAM database—this system was discontinued in 2017 and is not publicly accessible. It is possible that RSHQ could approach DMIRS for access to the data.

The Resource Regulator in NSW do not publicly report any exposure data to lead or blood lead analyses.

The HSE published a review of medical surveillance of blood-lead levels between 1992/93 and 2009/10 and an update in 2019/20. These reports showed that by 2019/20 0.3 % of workers reported blood lead levels above the HSE suspension level of 60 µg/dL and 1 % of workers under surveillance in excess of the action level of 50 µg/dL. The data also showed that smelting and refining had just over 20 % of male workers under surveillance with blood lead levels in excess of 25 µg/dL. There were no data reported for miners.

In the USA NIOSH has coordinated the Adult Blood Lead Epidemiology and Surveillance Program from 1994 to 2013. The most recent reporting of this program covers the period 1994-2012. These data are for employed adults. The data is reported across all industries and by state. It was not possible to identify mining or smelting separately nor the percentage of workers who were tested in total only the total number of employed persons. The data was reported as the number of cases blood lead levels exceeding either 10 or 25 µg/dL. Without knowing employment trends in lead risk activities, it is difficult to interpret the data. Overall, the prevalence rate has changed from 14.0 per 100,000 in 1994 to 5.7 per 100,000 in 2012 for blood lead levels in excess of 25 µg/dL. In 2012 22.5 per 100,000 exceeded 10 µg/dL. Data at this level of granularity was not collected before 2010. (Alarcon, et al (2015)).

A study by Koh et al (2015) collected personal exposure monitoring data and blood lead data from 175 papers containing 1111 sets of lead concentration summary statistics. No data was presented for metalliferous mining activities. For lead smelting the weighted arithmetic mean exposure measurement was 3.1 mg/m^3 and 54 µg/dL for blood lead.

11.11.2 Current data

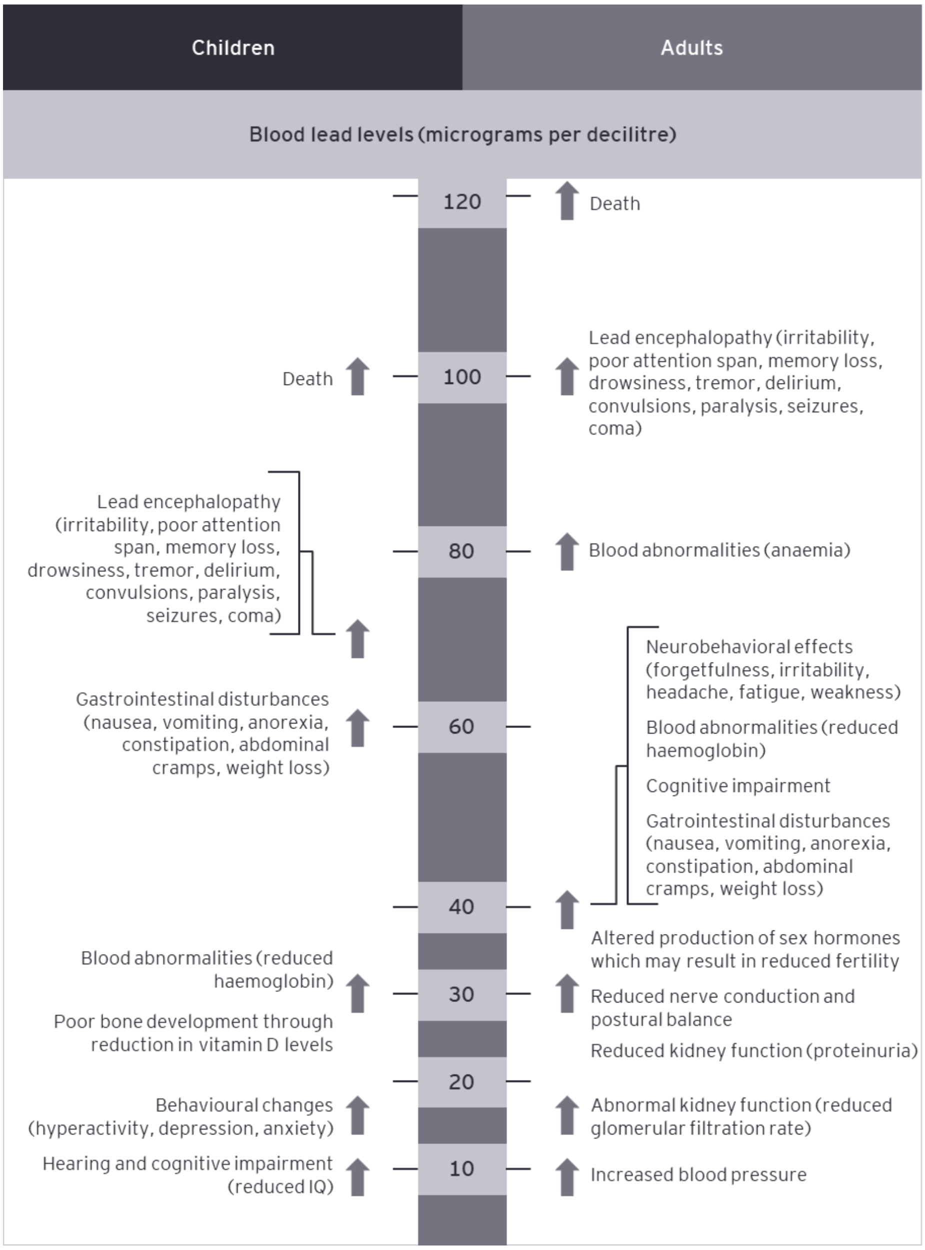
In 2018 the Australian Institute of Occupational Hygienists (AIOH) published a position paper—Inorganic Lead—Potential for Occupational Health Issues. This document is an update on the 2009 position paper and includes a review of recently published literature. It also supports the Safe Work Australia research and recommendations for a WES of 0.05 mg/m^3. It notes that harmful effects on many organs and bodily functions have been reported at blood lead levels greater than 10 µg/dL.

The AIOH recommended that there should be a system for managing and controlling exposures where blood lead concentrations exceed 20 µg/dL for males and 5 µg/dL for females of reproductive capacity. The transfer level should be 20-30 µg/dL for males and >= 10 µg/dL. For all new workers a blood lead test should be required and the result <= 20 µg/dL for males and <=5 µg/dL for females of reproductive capacity. An exposure guidance level of 0.03 mg/m^3 TWA is recommended. At levels in excess of this, a blood lead monitoring program should be required.

In 2015 The NHMRC issues an information paper: Evidence on the Effects of Lead on Human Health. This document provides details on the hazard posed by lead, including the mechanisms of lead absorption, and the associated health issues. The NHMRC reviewed the published evidence. Clear evidence was identified for adverse health effects as a result of blood lead levels greater than 10 µg/dL. An association was found between reductions in Intelligence Quotient (IQ) and academic achievement in children at blood levels less than this. For blood lead levels between 5 and 10 µg/dL, an association was observed between higher occurrence of behavioural problems (poor attention, impulsivity and hyperactivity) in children, increase blood pressure in adults (including pregnant women) and a delay in sexual maturation or puberty onset in adolescent girls and boys. The NHMRC concluded that if a person has a blood lead level greater than 5 µg/dL, their exposure to lead should be investigated and reduced.

Figure 12, copied below, from the NHMRC report summarises the potential health impacts as a function of blood lead levels.

Figure 12: Health effects of blood lead levels 10 micrograms per decilitre and higher.



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Mental health and suicide risks

12. Mental health and suicide risks

12.1 Overview

Summary of the health effects presented by the risk
Mental health and suicide risks are significant for the health of resources workers in Queensland. Exposure to psychosocial hazards—factors in the design and management of work that increase work-related stress—result in increased psychological distress. The varied, complex nature of how psychosocial hazards present in workplaces, paired with the cumulative health impacts of exposure to multiple psychosocial hazards, makes quantifying the specific impact of any individual risk challenging. The adverse impacts of exposure to psychological distress are critical for both individuals and workplaces. Consequences of exposure to psychological distress range from burnout, increased risk of mental illness and other adverse health effects, such as increased cardiovascular risk. Research in coal mines approximate that Australian mines lose $153.8 million annually in lost time due to exposure to psychological distress [40]. Most concerningly, exposure to high psychological distress can be deadly, as it significantly increases risk of suicidal thoughts, suicide attempts and successful suicide. The field's understanding of the true health impacts of exposure to these hazards is constantly evolving, however there is consensus that these impacts are under-stated and under-reported. Considering this, identifying, monitoring, and managing psychosocial risks in workplaces has become an increasing area of focus both nationally and internationally. It is a priority action area for Safe Work Australia, is a focus of Workplace Health and Safety Queensland, and has been the subject of several reports and publications produced by Australian resources sector regulators.
What we know about the risk (data from RSHQ and elsewhere)
Within the resources sector Mental health and suicide risks in the form of psychological distress poses significant threats to worker wellbeing across the resources sector, both through the demographic makeup of the sector (a high proportion of young, male workers working remotely) and the unique combination of psychosocial hazards workers are exposed to through work in the resources sector. Research suggests that resource workers have levels of psychological distress between two and three times that of the national average [15, 42]. ***Within FIFO workers*** Evidence strongly suggests that fly-in fly-out ('FIFO') work presents a major mental health and suicide risk. In research commissioned by the Western Australian Mental Health Commission, one third of FIFO experienced high or very high levels of psychological distress, almost double the incidence rates in non-FIFO workers and over three times greater than psychological distress in the general population[13]. Increased isolation, work-life disruption, relationship breakdowns, shift work and long swings and increased consumption of drugs and alcohol are seen as major contributors to this increased risk; FIFO workers are almost twice as likely to have consumed alcohol on any given day, and over twice as likely to have engaged in binge drinking in the previous 12 months [13].

How we can learn more about the impact of this risk in the resources sector in Queensland
Queensland is not unique in needing to address this issue. There is a body of evidence that is emerging from all jurisdictions showing that this risk needs to be addressed, yet consensus has not been reached as to how to best measure or monitor risk levels. There are little to no data available on true incidence rates of this health hazard in the Queensland context. What information is available is drawn from Workers' Compensation data, HPI (high-potential incident data), and notifiable incident data, which both misrepresent and underrepresent true incidence rates of mental health and suicide concerns. Due to the paucity of data available in Queensland, it is recommended that RSHQ be informed by research from the Western Australian Mental Health Commission [13] on incidence rates of psychological distress amongst resources and FIFO workers. These data provide a basis for understanding the high levels of risk resources workers are exposed to through the nature of their work in the industry as compared to the general population.

12.2 What is the health hazard?

Mental health is defined as *"a state of wellbeing in which the individual realises their own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to their community"* [1]. It comprises of emotional, psychological, and social components, and is both the absence of negative indicators (e.g., depression, anxiety, negative emotions) as well as the presence of positive indicators (e.g., life satisfaction, positive emotions) [2].

12.2.1 Mental health risk

In this report, "mental health risks" are factors that increase negative or reduce positive indicators of mental health. The primary outcome discussed in this review is ***psychological distress*,** generalised feelings of anxiety or depression. Psychological distress is a predictor of many negative mental health and wellbeing outcomes, with risk compounding with exposure to multiple risks [3].

12.2.2 Suicide risk

"Suicide risk" or suicidality refers to the risk of an individual [4]:

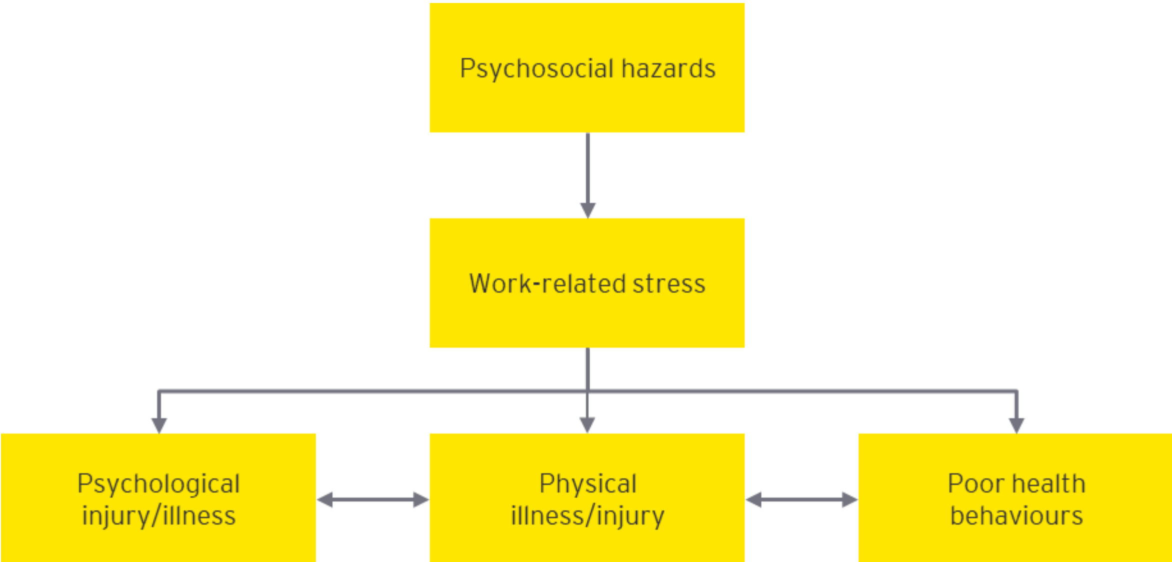
- Having serious thoughts about taking one's own life
- Making suicide plans
- Attempting suicide

Thoughts about suicide can be fleeting ("I'd be better off dead"), active ("I should kill myself") or involve planning and preparation ("I have the means and ability to complete suicide") [5]. Suicide risks can be split into "static" and "dynamic" factors. Factors based on mental health, gender and other demographic factors are 'static', while exposure to novel and/or extreme stressors an individual faces in the context of their daily life are referred to as dynamic risk factors [6].

12.2.3 Psychosocial hazards

Within a workplace context, mental health and suicide risks are often referred to as "psychosocial risks". Factors that contribute to psychosocial risk are referred to as **psychosocial hazards,** which are anything in the design or management of work that increases the risk of work-related stress. When not effectively managed, they increase psychosocial risk due to increased physical and/or psychological stress. These exposures can be frequent, but can lead to low to moderate stress, or be infrequent but create high levels of stress.

Figure 13: Interaction between psychosocial hazards, stress, and adverse outcomes. Adapted from Worksafe Queensland: Preventing and managing risks to work-related psychological health.



The following table outlines psychosocial hazards that can cause increased psychological distress relevant to the resources sector.

Table 15: The psychosocial hazards of relevance to the resources sector, drawn from Codes of Practice from Queensland [7], Western Australia [8] and New South Wales [9]).

Psychosocial hazard	Description of hazard
Workplace demands	Certain types of work that involve substantial and/or excessive physical, mental and emotional efforts required to do the job such as time pressure, excessive workload, repetitive or monotonous tasks, high mental workload, extended hours, roster length, shift rotation and exposure to emotionally distressing situations.
Low control	Low levels of control over how work is done, such as when work is scripted or computer paced; when workers have little control over break times or changing tasks; or when workers are not involved in decision making that affects them or their clients. This can also involve lack of control over accommodation arrangements, including access to privacy, control over sleep schedule and other daily tasks (mealtimes, showering).
Job insecurity	Job insecurity refers to employees' perceptions and concerns about potential involuntary job loss. Job insecurity implies uncontrollability and feelings of powerlessness, which are known to be related to poor well-being [10]. Job insecurity is a major challenge for workers in the resources industry; workers are increasingly exposed to high market volatility, as characterised by the economic boom, and bust cycle and subsequent job insecurity that accompanies such economic circumstances.[11]
Low support from colleagues and/or supervisors	Lack of support in the form of constructive feedback, problem solving, practical assistance, provision of information and resources. This can include direct feedback and support, access to appropriate equipment or adequate training.

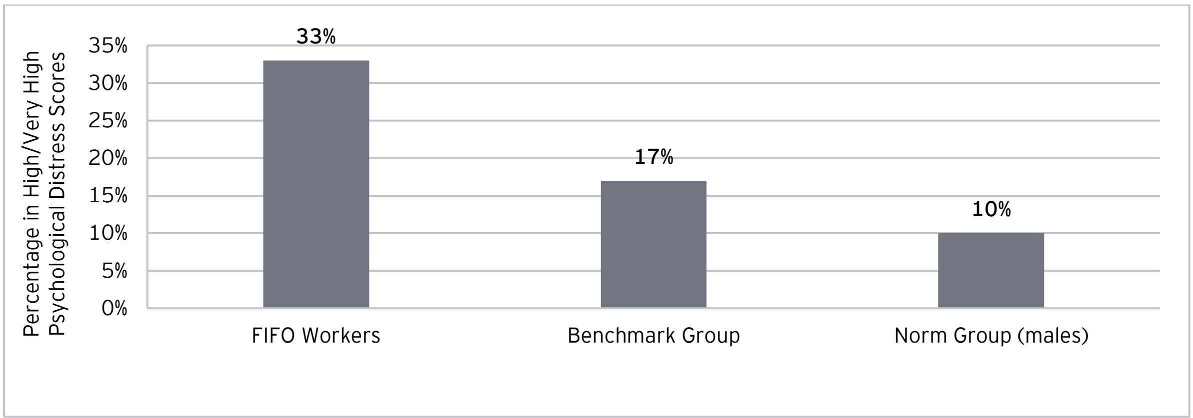
Psychosocial hazard	Description of hazard
Role-related stressors	**Lack of role clarity**; unclear or constantly changing management expectations about the responsibilities of the job or where required information is not available to the worker. **Role conflict:** Incompatible expectations or demands placed on workers by different workplace stakeholders, or where a worker has conflicting job roles, responsibilities, or expectations.
Effort-reward imbalance	Jobs where there is an imbalance between workers' efforts and associated recognition and reward (material, personal and social), a lack of recognition of good performance and/or a lack of opportunity for skills development or where skills and experience are underused
Exposure to traumatic events	Exposure to an event, or threat of an event, that is deeply distressing or disturbing for the individual including death, threat to life, near-misses and/or self-injury.
Isolated work	Working in an environment where there are few or no other people around. This may lead to limited opportunities for problem sharing and feedback; a perception of increased responsibility for decision making; limited opportunities for socialisation and barriers to communication.
Exposure to inappropriate workplace behaviours	Exposure to behaviours that are unreasonable, offensive, intimidating or may cause distress, such as witnessing or experiencing situations involving violence or aggression; bullying; harassment; conflict and/or discrimination.
Poor organisational justice	Unfairness, inconsistency, bias, or lack of transparency in the way procedures are implemented, decisions are made, or workers are treated. This can appear as (or perceived to appear as) inconsistency in the application of organisational policies and procedures; unfairness in the allocation of resources and/or bias in the approval of worker entitlements (e.g., annual leave)
Poor organisational change management	Uncertainty about changes in the organisation, structure, or job, or where the approach to change is unstructured. This is usually facilitated through poor or inadequate communication relating to change or insufficient consultation with workers.
Exposure to extreme environmental effects	Exposure to conditions that influence worker comfort and performance, such as extreme temperatures, noise, poor air quality light and humidity.
Exposure to adverse natural events	Given the remote nature of much of resources work, a natural event (e.g., cyclone, flooding, bushfire) that can restrict travel, constrain activities, interfere with communications and/or create uncertainty in the workforce and families
Remote work	Working and living in a remote location may mean: ► Limited access to reliable communication technology ► Limited access to recreational activities ► Interruption and reduced capacity to fulfil usual roles and commitments in family, community, and other social networks ► Challenges with reintegration to home and work environments after being away from them ► Fewer opportunities to escape work issues and work relationships

12.2.4 FIFO work as a psychosocial hazard

Evidence strongly suggests that fly-in fly out ('FIFO') work presents a major mental health and suicide risk. Even when accounting for associated risks such as age and education, FIFO workers are at greater risk of mental ill health than those in the broader resources sector and the general population. [12]

In research commissioned by the Western Australian Mental Health Commission, one third of FIFO experienced high or very high levels of psychological distress, almost double the incidence rates of a benchmark group of non-FIFO workers and over three times greater than psychological distress in the general population [13].

Figure 14: Comparison of "high" or "very high" scores of psychological distress between FIFO workers, a benchmark group of mining workers, and a norm group sourced from the general population as measured by the K10 [61]. Source: Western Australian Mental Health Commission [13].



Within the same study, FIFO workers also indicated significantly riskier drug and alcohol use as compared to residential workers or the general population. FIFO workers were more likely to

- Consume alcohol on any given day (71% of FIFO workers vs. 43% of resources workers vs. 26% of males in the population)
- Binge drink - 11+ standard drinks on a single drinking occasion in the past 12 months (44% vs. 22% vs. 16.1%) and
- Take illicit drugs in the last twelve months (29% vs. 12% vs. 19%)

FIFO workers are exposed to the following psychosocial hazards in greater amounts and intensities than the general working population in the resources sector, although these risks are applicable to those working in the resources sector more broadly [12]. As outlined previously, the nature of psychological distress means that each exposure to additional stressors has a compounding effect on the level of distress, and therefore an increasingly increased risk of mental ill-health.

12.2.4.1 Isolation

Isolation (physical, social, and emotional) is a major concern in FIFO work and has an important influence on FIFO workers' mental health and suicide risk. Difficulty in creating or maintaining a social network, and separation from important events both causes and exacerbates a sense of isolation among FIFO workers, and is strongly associated with negative mental health, increased psychological distress, and reduced wellbeing across multiple studies. [13-17].

Relative to non-FIFO workers, FIFO workers have also been found to be less likely to report or seek help for mental health concerns [18]. Remote working, long shifts and the disruption of relationship building with health care professionals also decrease access to support [14].

12.2.4.2 Job insecurity

Job insecurity and the subsequent psychological distress is particularly pertinent for FIFO workers; in Queensland, 23% of FIFO workers expect to lose their jobs, compared to 9.5% of the general population [19]. High rates of mental health stigma in the resources industry may also exacerbate the effects of job insecurity on FIFO worker mental health, according to submissions to a Queensland Parliamentary Inquiry [14]. This is because individuals are less likely to disclose due to concerns on future job prospects and are concerned that their confidentiality would not be maintained at workplace clinics.

12.2.4.3 Work-family disruption

Beyond the deleterious effects of isolation more broadly, a central stressor of the FIFO working pattern is the disruption to the family unit, where separation and disruption to routine leads workers and their families to experience higher rates of distress, parenting challenges, family stresses and relationship dissatisfaction [14].

Workplace psychosocial hazards are a major contributor to this disruption. Workplace demands such as long swings; shift work and the personal health repercussions of extended working hours can lead to 'work-family spill over'. The consequence of these workplace demands (such as high workload, work pressure and physical stressors) combined with family obligations can result in a lack of quality time for self and family, physical and emotional strains, and negatively impact productivity at work [20].

Another psychosocial hazard—the consequences of remote work—also contribute to work-family disruption. Research suggests that the feeling of 'missing out' on family events and children's milestones has a negative impact on FIFO workers and their families[21] and these family-based stressors (including relationship breakdown or challenges) are a significant lifestyle stressor for many FIFO workers. This is particularly concerning due to the link between relationship challenges & breakdowns and increased suicide risk amongst males [22].

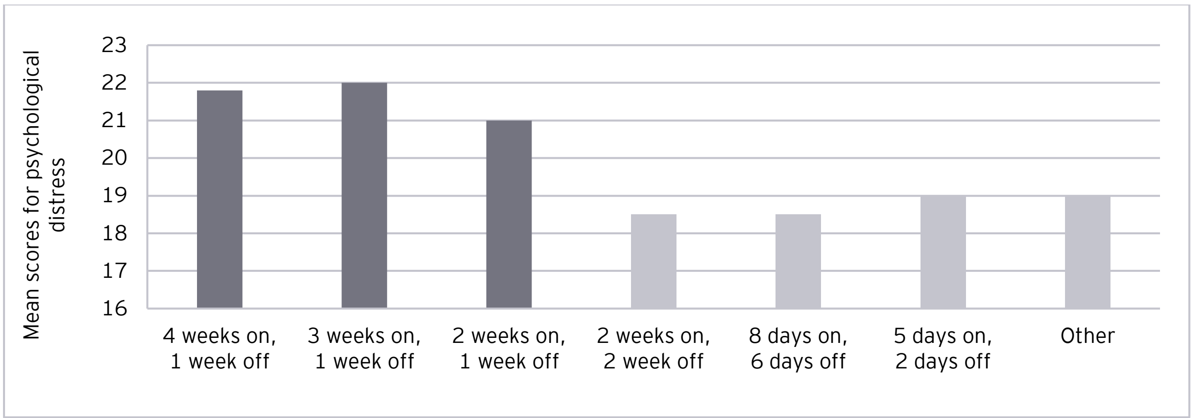
12.2.4.4 Shift length and roster structure

Research suggests shift and roster structure have a meaningful impact on psychological distress in FIFO workers. In a study by the Western Australian Mental Health Commission, FIFO workers on even-time and shorter rosters (i.e., 2 weeks on/2weeks off, 8 days on/6 days off, 5 days on/2 days off) reported significantly better outcomes on all mental health and wellbeing measures compared to FIFO workers on longer rosters with less time for recovery (e.g., 4 weeks on and 1 week off, 3 weeks on/1 week off, 2 weeks on/1 week off) [13].

Workers on high compression rosters (1-4 weeks on/1 week off) report greater dissatisfaction with shift lengths, more conflict in relationships, and lower levels of work-life balance than any other Australian industry group [16].

Longer working hours are also associated with poorer mental health outcomes. Workers who worked more than 48 hours a week had significantly worse mental health than those working less than a reference group of 35-40 hours a week [23].

Figure 15: Comparisons of psychological distress scores of a FIFO population, comparing roster structures. Measured using the K-10 scale of psychological distress, where scores 10-15 are considered low, 16-21 are considered moderate, 22-30 are considered high and 31-50 are considered very high. Source: Western Australia Mental Health Commission [13]



12.2.4.5 Camp conditions

Camp conditions play a significant role in worker mental health and wellbeing. Workers who have access to a permanent room report significantly better mental health and wellbeing compared to other accommodation arrangements. Poor campsite conditions, such as poor quality of accommodation and food, unreliable internet connection, and the many rules and regimes can lead FIFO workers to feel "institutionalised", leading to detrimental effects on mental health. The importance of communicating with family and friends whilst on site, private lodgings and the availability of internet and landlines are significantly linked to mental health and wellbeing [13].

12.2.4.6 Off-shore work

The offshore working environment is characterized by a range of psychosocial hazards such as difficult working and living conditions, long working days and shift work (including night work) as well as physical stressors like noise, ergonomics and chemical hazards.[24] Off-shore workers are exposed to a range of unique physical hazards, including threats to the structural integrity of the installation, fire, explosion, blowout, accidents associated with the transport of personnel and supplies, dangers associated with drilling operations, diving accidents, and falls. Findings show that about 35% of offshore personnel feel unsafe with regard exposure to hazards; this fear of unsafety has been linked to increased risk of mental ill-health. [25]

12.2.5 Other relevant psychosocial hazards

12.2.5.1 Mental health stigma

Mental health stigma is the negative and inaccurate perception of mental illness by the general public. Workers experience significantly worse mental health and wellbeing across all measures when mental health issues were stigmatised in the workplace [13].

Mental health stigma is a significant challenge within the resources sector [26] and is a source of psychological distress amongst remote and isolated workers [16]. There is a perception that mines are not committed to supporting worker mental health [15]. Mental health support in the resources sector is seen by many workers as tokenistic, stigmatised or generally inadequate, and that their jobs would be at risk if they were to access support [27].

12.2.5.2 Organisation size

Although job demands and psychosocial hazards are workplace agnostic (i.e., they can theoretically appear in any workplace), workplaces with fewer employees, less access to support, less system and personnel redundancy and less developed systems, structures and policies are more at risk of employees experiencing psychosocial hazards within the workplace [28].

As such, workers in the types of operations that typically have lower headcounts, such as quarrying and biogas, are more likely to be exposed to psychosocial hazards such as high work demands, poor organisational support, lack of supervision, job insecurity and role related stressors. Smaller operations are also more likely to employ one-off contractors and be more influenced by seasonal differences in workload, amplifying the negative effects of job insecurity across the organisation and less diligence in managing psychosocial hazards such as consultation [3].

12.3 What are the consequences of exposure?

12.3.1 Consequences for individuals

For individuals, increases in psychological distress has been linked to negative individual outcomes, including increased risk of job stress, strain, and burnout [29], increased risk of mental illness (anxiety, depression, post-traumatic stress disorders) [30] decreased physical health, including increased risk of cardiovascular disease [31] and suicidal ideation, behaviours, and successful suicide. [32]

Within the resources sector, research has linked exposure to the following psychosocial hazards to a range of negative mental health outcomes:

- Low choice/control over decisions and job tasks are significantly associated with poorer mental health and wellbeing amongst mining workers [13] and low autonomy over shift schedules can have detrimental mental health impacts at both work and home for FIFO workers [33].

- Job insecurity, both in Australia and internationally, has been associated with adverse health outcomes; in particular mental health.[13, 34, 35] In a mining population, job insecurity contributed significantly to levels of worker psychological distress[15] and is linked to poorer workplace health and safety performance[36].

- Remote work, due to the resulting social isolation, is particularly damaging to worker mental health and wellbeing [14, 20, 37].

- A lack of support from line managers and co-workers is linked to negative mental health outcomes in a FIFO sample [13].

- Exposure (particularly repeated exposure) to traumatic events is linked to risk of psychological illness and/or injury [38].

- Poor organisational change management, particularly lack of consultation in the resources sector has been linked to negative worker mental health outcomes [14, 37].

- Exposure to extreme environmental effects can increase physical strain, disrupt sleep, and contribute to fatigue, and increased psychological stress [39].

12.3.2 Consequences for workplaces

Mental ill-health has substantial economic and productivity ramifications for industry, with higher absenteeism, presenteeism (people who attend work despite being sick whereby their productivity is reduced) and reduced productivity. Approximately 35–45% of workplace absenteeism is attributed to mental health problems and presenteeism amongst those with mental ill-health costs workplaces up to 18 lost workdays per year [40]. Research has also observed higher injury rates in those suffering from mental ill-health, and in those experiencing heightened psychological distress [8, 11, 41].

In Australia, in 2013–2014, the estimated cost of mental ill-health to the public and private sectors and individuals was $974 million, with an annual cost (because of lost productivity) of $11.8 billion [43]. Within a study of 1456 coal mining staff across eight mining sites in Queensland and NSW, estimated annual value of time lost due to psychological distress was $4.9 million ($0.61 million per mine); across the entire Australian Coal Mining Industry, the total annual costs attributable to psychological distress were $153.8 million[43]. Given the escalation in mental health challenges and psychosocial hazards observed in society at large, the true cost to individuals, the resources sector, and society, these figures have very likely increased since the completion of this study.

12.4 Who is exposed? And how are they exposed?

Suicide is a significant threat to Australian lives. Just over 3000 people are lost to suicide each year in Australia, an average of more than 8 people per day. It has been the leading cause of premature death in Australia's young adults, accounting for around one-third of deaths among people aged 15-24[44]. At some point in their lifetime, over 2.1 million Australians aged 16-85 years had serious thoughts about taking their own life; over 600,000 made a suicide plan; and over 500,000 attempted suicides [45].

The broad nature of mental health and suicide risks mean that any worker has the potential to be exposed to one or many risks in any workplace. However, the unique demands of working in the resources sector pose a sizable risk to worker mental health, due to both the amount and variety of risks that workers are exposed to.

The consequences of this increased exposure are severe. Research suggests that psychological distress occurs amongst resources employees (nationally) significantly more than the general Australian population, based on research conducted in coal and metalliferous mining workers. One study found psychological distress occurs in mining industry workers at a rate of almost three times the national average [15], while another found those working in mining report moderate to high psychological distress (44.4%) significantly more than the general population (27.2%) [45].

Determining true rates of psychological distress, mental ill-health and/or suicide amongst resources workers is challenging; true rates of attempted and/or successful suicide in remote working environments are particularly difficult to assess as only incidents occurring during work hours are likely to be captured as a notifiable incident. Incidents that do not occur during work hours or on work sites are much less likely to be reported as relating to the workplace.

Although research has been conducted within a limited population of the resources sector, given the similarities in demographic factors, shift structure and psychosocial pressures present across the resources sector, we present the view that these risks are relevant across the resources industry beyond coal and metalliferous mining. One exception to this may be the off-shore petroleum and gas industry; data from Monash University's Health Watch [65] indicates that both men and women in this cohort suffered from lower rates of death by suicide than the general population.

12.4.1 Individual risk factors

The reasons for this increased rate of psychological distress are complex and interrelated. The following section outlines a number of individual factors that contribute to elevated risk of psychological distress and/or suicide risk not noted in the previous sections.

12.4.1.1 Age and gender

Demographics of resources workers (particularly FIFO workers) are at a higher risk for suicide based on gender and, age and geographic location. Males, particularly young males are particularly prone to negative mental health [34]. There is evidence that younger workers experience increased risk; the risk of high anxiety and stress is two times higher for workers who are young (18-33 years) compared with older workers in a sample of remote mining and construction workers [16].

About three-quarters of people who die by suicide are male and deaths from intentional self-harm occur among males at a rate three times greater than that for females [46]. Over one-third of deaths among people aged 15–24 years are due to suicide and suicide is the leading cause of death for Australians aged 15–44 years [22]. Regional communities have significantly higher rates of suicide (15.9 per 100 000 people) than capital cities (10.3 per 100 000 people) [22].

12.4.1.2 Job role and contract type

Job role and contract type also influence mental health outcomes. Those with lower educational attainment are at higher risk of negative mental health outcomes [13] due to reduced academic, cultural and economic resources. Contract workers are at higher risk, as they may be exposed to increased stressors, with less flexible, longer roster cycles and the potential to be "shuffled" between sites on their days off [14]. Managers are more likely to experience heightened psychological distress than non-managers [15], likely due to the increased demands of their role. Research by the Western Australian Mental Health Commission found that within a FIFO population, mental health and wellbeing was lowest for contractors, construction workers, and camp, catering, and logistical staff [13].

12.4.1.3 Drug and/or alcohol use

A history of drug and alcohol problems increases risk of mental health concerns [13]. There is a reciprocal relationship between "risky" drug or alcohol use and psychological distress; increased use of drugs and/or alcohol increases risk of psychological distress at work[15] and higher psychological distress has likewise been linked to risky drinking behaviours[13]. One of the mechanisms that drug and alcohol use reduces physical and mental health is through disruptions to sleep. This reduced quality of sleep in turn contributes to long-term negative physical and mental health effects and other factors associated with increased psychological distress [8].

Risky alcohol use has been identified as being at considerably higher levels in Australian miners (coal and metalliferous) than both national and international averages. More than half of the male (53.7%) and almost one-third of the female (29.3%) participants consume alcohol above the threshold considered risky or hazardous.[47]

12.4.1.4 Fatigue

Outside how fatigue contributes to other safety concerns, workplace fatigue is linked to increased psychological distress [48]. Fatigue's negative impact on emotional regulation [49] and cognitive tasks such as problem solving [50] poses mental health risks. Fatigue has also been associated with increases in workplace psychosocial hazards such as increased aggression [51].

12.4.1.5 Previous mental ill-health

A history of personal mental health concerns, including depression and anxiety, increases risk of psychological distress in the workplace [15]. From 2017 to 2019, the most identified psychosocial risk factor for suicide and/or suicide ideation across the Australian population was a personal history of self-harm [22].

In other industries (e.g., first responders), screening for prior mental illness has been implemented as a control for this risk, however there is little evidence to suggest this control is effective [52]. As a result, it is difficult to ascertain the extent to whether screening for mental health in the mining industry is effective as a prevention approach.

12.4.1.6 Individual circumstances

Psychosocial factors that influence suicide in males include a disruption of family by separation and problems in a relationship with spouse or partner. Loneliness and feelings of social isolation are significant risk factors for suicidal intention and suicidal behaviour, alongside exposure to anti-social workplace behaviours (bullying; harassment), exposure to potentially traumatic events and a perception of feeling "trapped" and lacking autonomy around their choice of employment [13].

12.5 What are the current Queensland regulatory requirements for the management of the hazard?

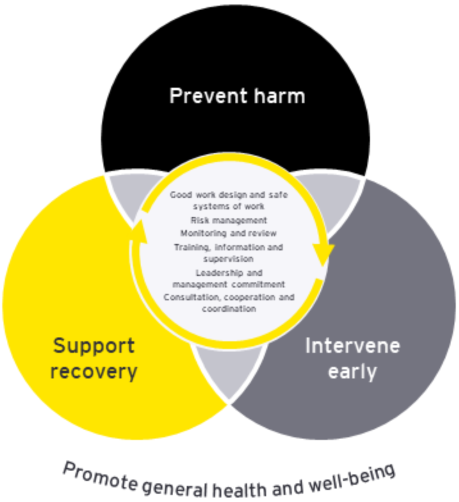
Standards and compliance responsibilities for psychological health fall under various pieces of legislation including the Mining and Quarrying Safety and Health Act 1999, Mining and Quarrying Safety and Health Regulation 2017, Coal Mining Safety and Health Act 1999 and the Coal Mining Safety and Health Regulation 2017[69]. Where these regulations do not apply, workers are covered by the *Work Health and Safety Act 2011*[52].

Section 42(1)(b) of the Coal Mining Safety and Health Regulation 2017 mentions psychological impairment including stress. Guidance relating to the Work Health and Safety Act has indicated that safety officers and PCBUs have obligations to assess, monitor, mitigate and (where possible) eliminate psychosocial hazards in workplaces to reduce risk of psychological injury.

The "*How to Manage Work Health and Safety Risks Code of Practice 2021*" [53] sets the standard for systematically identifying assessing, controlling, and reporting health and safety risks in the workplace within the Queensland context, under which mental health and suicide risks fall.

Safe Work Australia outlined an approach to workplace psychological health and safety through preventing harm, intervening early, and supporting recovery. This reflects growing community recognition of unaddressed mental health needs and particularly the public attention to concerns about suicide among males in the resources industry [11]. Worksafe Queensland has released an analogous approach (Mentally healthy workplaces toolkit) which includes *People at Work* tool—a validated, evidence-based psychosocial risk assessment process with associated benchmarking [68].

Figure 16: A systematic approach to supporting psychological health and safety in workplaces. Source: Safe Work Australia



Shifting Minds: Queensland Mental Health Alcohol and Other Drugs Strategic Plan 2018-2023[54] sets the five-year direction for a whole-of-person, whole-of-community, and whole-of-government approach to improving the mental health and wellbeing of Queenslanders.

This Strategy highlights the importance of prevention of mental ill-health in workplaces through the "*Invest to Save*" pillar. It highlights how workplaces can act as places to enhance mental health and wellbeing and provide opportunities to intervene early. In particular, it speaks to the role that workplaces can play in strengthening mental health by increasing awareness of the critical importance mental health and wellbeing at work; guiding workplaces on systematic approaches to workplace mental health and problematic AOD use; increasing the capability of Queensland employers to create inclusive and mentally healthy workplaces; and exploring options for providing incentives for workplaces and industries to adopt mentally healthy workplace practices.

The Strategy also indirectly addresses workplace mental health and suicide risk by highlighting the barriers for those with mental illness gaining employment, such as an inflexible welfare system that reduces incentives to return to work, limited employment supports, discriminatory employment practices, and a lack of appropriate workplace adjustments.

The Queensland Suicide Prevention Plan identifies workers in the mining industry as being vulnerable and has an action to identify suicide prevention initiatives for vulnerable workers including males in the resources sector.

12.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Jurisdictions with an active resources sector are recognizing that psychosocial hazards are significant. These jurisdictions are investing in better understanding psychosocial hazards, specific to the contexts of their demographics and geographies. They are looking at their industries and trying to get them better equipped to manage this complex issue. What follows is not a comprehensive review of all the initiatives, but it includes specific examples of what we've looked at for this report. Looking across the various jurisdictions, we see an emerging trend towards trying different approaches to address and manage the hazards, but as yet there is no established "tried and true" methodology that stands out as the most effective. As more jurisdictions place increased focus on these risks, practitioners and regulators will have a broader base of evidence and initiatives to draw upon to manage this risk more effectively.

12.6.1 Western Australia

Off the back of a Parliamentary Inquiry into suicide in FIFO workers and extensive research into prevalence rates of psychological distress and suicidality in resources workers [13], Western Australia has placed increased focus on mental health and suicide risk in the resources sector. Based on of this research, WA is beginning to take steps towards addressing these risks in the sector.

Western Australia Department of Mines, Industry Regulations and Safety has developed a mentally healthy workplaces auditing tool and technical guide to assist duty holders in meeting their work health and safety legal obligations as outlined in the Code of Practice Mentally Healthy Workplaces for Fly-in, Fly-out Workers in Resources and Construction Sectors. This audit tool provides organisations with clear guidance as to how they could demonstrate they are controlling psychosocial hazards within their organisation [3].

12.6.2 New South Wales

In 2021, Safe Work NSW released a Code of Practice that provides practical guidance on how organisations can better manage psychosocial hazards at work [9]. This is an industry-wide Code of Practice to formally clarify the legal responsibilities businesses have to address hazards in the workplace that have the potential to cause psychological or physical harm under the "*Work Health and Safety Act 2011*". No specific guidance is provided for the resources sector.

12.6.3 Comcare

Comcare acknowledges the impact of psychological injury on government employees. According to recent data, psychological injury is a major source of lost time and compensation costs within the Comcare scheme. Psychological injury accounts for approximately 11 per cent of claims and around 30% of the total cost of claims.[56] Comcare offers guidance, strategies and training as to how organisations can prevent psychological injury through "*Working Well: An organisational approach to preventing psychological injury*", however this guidance may be dated having last been updated in 2008[57].

12.6.4 Minerals Council of Australia

In recognition of the importance of mentally healthy workforces, Minerals Council of Australia has created a Blueprint for Mental Health and Wellbeing [58] in the Australian minerals sector. The Blueprint outlines four key areas that enable industry to promote mentally healthy workplaces:

- Implementing prevention controls: Prevent onset of mental ill-health through addressing risk and protective factors and promote good health and wellbeing in all workers
- Culture: Create a culture that supports wellbeing across sites and industry
- Capacity: Increase knowledge and skills to identify and respond to mental ill-health in the workplace
- Recovery preparation: Promote recovery through return to work and reduce stigma associated with mental ill-health

12.6.5 International Organization for Standardization

The International Organization for Standardization (ISO) is an international standard-setting body that develops and publishes worldwide technical, industrial, and commercial standards. In 2021, ISO released *ISO45003: Occupational health and safety management— Psychological health and safety at work— Guidelines for managing psychosocial risks* [70].

This standard covers the management of psychosocial risk within an occupational health and safety (OH&S) management system based on the standard *ISO 45001: Occupational health and safety management*. This global standard is designed to provide organisations of all sizes guidance on ways to develop, implement, maintain, and continually improve the health, safety, and wellbeing of workplaces.

12.7 Industry controls

The following section outlines commonly used controls for mental health and suicide risks in workplaces implemented by employers in the resources sector.

12.7.1 Employee Assistance Programs (EAP) and other support services

EAP services offer anonymous, free psychological and other services to employees, typically delivered by a third-party contracted by the organisation. Often these services are also made available to family members of employees.

Research suggests that despite the presence of EAP services at many mine sites, there is a critical gap between those with mental health challenges and choosing to access support [42]. For example, in a study of Australian FIFO workers, it was found that stigma is a major barrier, so despite being aware of the services only 5% of workers had accessed the services in the previous 12 months [59] suggesting a critical gap between need for services and accessing them.

Other support services advertised by organisations include mental health and suicide helplines (Lifeline, Beyond Blue and Suicide Call Back), however awareness amongst workers is also low despite how frequently those services are communicated across the sector [13] and the aforementioned mental health stigma within the industry is likely contributing to low uptake of these services.

12.7.2 Training

Training is another common control within industry. Within this context, training generally includes mental health awareness training aiming to promote help-seeking behaviour and reduce mental health stigma. Other training focuses on supervisors and leadership training, aiming to promote an environment that promotes mental health and wellbeing. These trainings often focus on anxiety and depression symptoms, and how to have effective mental health conversations.

Mates in Mining [60] is a suicide prevention charity offering industry-backed, research-based suicide prevention and support for the mining industry. The evaluation of the Mates in Mining 'Working Well—Mental Health and Mining' project found the programme was well received and identified positive changes in knowledge, attitudes and help-seeking behaviours in workers, as well as supervisor confidence to identify and effectively engage employees in mental health conversations [11].

12.8 What are the current exposure standards and how is the hazard measured/evaluated in the workplace?

For the preparation of this report, the only measures available to the review across workplaces were workers' compensation data. Defining any one exposure standard is complicated by the interrelated, complex, and compounding nature of psychosocial hazards and psychological risks. We are aware that industry does collect leading indicator data on psychosocial hazards (such as health monitoring data), but these data were not made available to reviewers, nor are there currently any formal requirements (to our knowledge) for industry to provide these data to RSHQ.

A tool that may be valuable in measuring psychological distress in the workplace is the Kessler Psychological Distress Scale (K10) [61]. The K10 is widely recommended as a simple measure of psychological distress and as a measure of outcomes following treatment for common mental health disorders. The K10 is in the public domain and is promoted on the Clinical Research Unit for Anxiety and Depression website (www.crufad.org) as a self-report measure to identify need for treatment.

The K10 is used in the rail industry as an ongoing health monitoring tool. The tool aims to identify workers with significant levels of psychological distress so that they may be appropriately managed with respect to their work and their ongoing health and wellbeing. A cut-off score of 19 is the point at which medical practitioners will initiate a mental health intervention for Safety Critical Workers in the rail industry, due to the importance of mental health for safety critical work [66].

For reference, the extensive research conducted by the Western Australian Mental Health Commission [13] indicated that the average level of psychological distress amongst FIFO workers sat above this threshold [mean=19.36]. Further to this, one-third of FIFO workers (34%) had moderate to high risk of a mental health challenge based on scores on the K10. Almost two-thirds (63%) of FIFO workers in this sample would have potentially required intervention as per the National Rail Standards cut-off point. The proportions of residential resources workers showing similar levels of distress was lower (44% and 17% respectively), but still double the rate of a benchmark population not working in the resources sector.

12.9 What health monitoring data is currently available to RSHQ?

The data sources that track mental health and suicide data are limited to workers' compensation, long term injury claims, and high potential incident data, and as such provide limited insight into the true state of mental health and suicide risk in organisations. In summary, these data reveal little in terms of true trends relating to psychological injury and do not cover the broad range of potential causes of psychological injury as per our most up-to-date understanding of psychosocial risk management (for reference, see NSW, QLD and WA Codes of Practice for managing psychosocial hazards in the workplace).

12.9.1 Workers' compensation data

Between 2016 and 2021, 5.4% of accepted workers compensation claims within the mining, explosives, petroleum and gas and quarries sectors were relating to Psychiatric / Psychological injury, the majority of which were related to exposure to traumatic incidents, workplace harassment and bullying, or workplace strain. This appears to be higher than the general Queensland population; in comparison over the period spanning 2013–14 to 2017–18, 3.4% of all accepted claims across Queensland related to mental health [67].

These claims likely underrepresent true incidence rates of negative mental health outcomes and as such, it is challenging to draw inferences or trends from these data. According to the recently released Productivity Commission Inquiry Report into Mental Health, mental health-related workers' compensation claims are up to ten times more likely to be rejected than non-mental health claims (24-60% verses 6-10%) [41]. In addition, Queensland has the lowest proportion of accepted mental stress claims compared to other states and territories [41].

Table 16: Summary of accepted disease claims in Queensland mining, explosives, petroleum and gas and quarries sectors.

Psychiatric/Psychological Injury	2016/17	2017/18	2018/19	2019/20	2020/21	Total
	20	28	26	59	13	146
(No category provided)				10	13	23
Being hit by falling objects				1		1
Exposure to a traumatic event	6	9	3	24		42
Exposure to workplace or occupational violence		2	1	3		6
Slide or cave-in				1		1
Suicide or attempted suicide		1				1
Vehicle accident	1	1	2	1		5
Work pressure	6	6	5	8		25
Work related harassment and/or workplace bullying	6	5	6	4		21
Total number of accepted claims (all)						**2706**

Linking psychological or psychiatric illness to a single acute incident (e.g., a traumatic event), is misrepresentative of how psychological injury or illness emerges; psychological injury often emerges through long-term exposure to less acute stressors. There is little to no information within these reports to provide specific information relating to cause and effect, the context in which the incident occurred, and any work-related factors that may have contributed to the event.

When reviewing incident data, there is evidence that incidents are being misclassified. For example, cases of suicide or self-harm that occur off worksite or in off-work hours, but within camp, have been labelled as "non-work-related incidents" within HPI data. The nature of this available data makes it difficult to determine exactly how many of these cases were attributable to suicide or self-harm versus other causes, e.g. a cardiovascular event.

Lastly, the nature of these data only allows them to act as inaccurate, lagged indicators of mental health and/or suicide risk as by the time these claims appear, the event has already happened. Due to this, workers' compensation data alone is inadequate for assessing, monitoring and/or controlling psychosocial risks across the sector.

Trends in these data also differ from trends in Queensland's Workers' Compensation claims. Queensland data (between 2013–14 to 2017–18) relating to workers' compensation claims indicates most psychological injury claims in the general workforce relate to work pressure.

Exposure to traumatic incidents (which account for 29% of all claims in the mining, explosives, petroleum and gas and quarries sectors) account for only 11% of claims in Queensland-wide data. One interpretation of these data is that workers in the resources sector are exposed to higher rates of traumatic incidents than the general population. Another interpretation is that *only* highly traumatic incidents are being reported as they relate to mental health and suicide.

Other notable comparisons are the potential underreporting of workplace violence (23% in general population vs. 4% in resources sector) and workplace harassment/bullying (22% vs. 14%). The differences in these trends should not be interpreted that the resources sector does not suffer from cases of bullying, harassment, and occupational violence. Rather, considering the make-up of the sector—a young, male population with high levels of mental health stigma and norms relating to self-reliance—this suggests chronic under or misreporting of workplace related psychosocial hazards. As such, workers' compensation data cannot be considered reliable even as a lagging indicator of mental health and suicide risk.

Table 17: Breakdown of claimable injuries relating to psychological injury and illness from Safe Work Queensland Data 2013–14 to 2017–18 as compared to accepted disease claims in Queensland mining, explosives, petroleum and gas and quarries sectors.

Claimable injury (psychological/psychiatric)	Proportion (All Accepted Qld Claims)	Proportion (mining, explosives, petroleum and gas and quarries
Work pressure	31%	17%
Exposure to workplace or occupational violence	23%	4%
Work-related harassment and/or bullying	22%	14%
Exposure to a traumatic event	11%	29%
Other mental stress	4%	-
Vehicle accident	3%	3%
Sexual/racial harassment	3%	-

12.10 Emerging risks—climate change as a health and safety hazard

People's anxiety and distress about the implications of climate change have the potential to undermine mental health and well-being. The U.S. Global Change Research Program is a U.S. federal initiative mandated by Congress to coordinate federal research and investments in understanding the forces shaping the global environment, both human and natural, and their impacts on society.

This program released a report outlining the ways in which exposure to climate- and weather-related natural disasters can result in mental health consequences such as anxiety, depression, and post-traumatic stress disorder [62]. Extreme heat also increases both physical and mental health problems in people with mental illness, raising the risk of disease and death. In part, that's because many psychoactive prescription medications impair the body's ability to regulate temperature.

The expanding research literature on climate change and mental health includes increasing evidence that extreme weather events—which are more frequent, intense, and complex under a changing climate—can trigger post-traumatic stress disorder (PTSD), major depressive disorder (MDD), anxiety, depression, complicated grief, survivor guilt, vicarious trauma, recovery fatigue, substance abuse, and suicidal ideation [63].

For workplaces in the resources sector, this emerging risk may have the following implications:

- Physical and psychological pressures such as extreme heat and adverse weather may become more common, requiring more effective and extensive controls for these risks.
- A workforce more likely to experience mental ill-health, resulting in knock-on effects on other health and safety areas.

Impacts on individual and organisational productivity and health and safety performance; for example, extreme natural events such as fire can reduce air quality to a point where work must be stopped [64].

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Musculoskeletal disease

13. Musculoskeletal disease

13.1 Overview

Summary of the health effects presented by the risk
Dysfunction of the soft tissues of the human body (muscles, nerves, tendons, and ligaments) is commonly termed *musculoskeletal disease* (MSD) *or musculoskeletal disorder* (MSD). The two terms are used interchangeably. Many International Classification of Disease diagnoses are used to describe MSDs. This makes using lagging indicator data such as workers' compensation information problematic for informing decision making for the prevention of MSDs. ► MSDs result in both acute and chronic physical and psychological impacts to workers. These health impacts subsequently impact productivity through reduced capacity to work. ► Physical impacts include loss of joint function, including strength and range of motion, loss of endurance, loss of control of movement, and reduced sensitivity or numbness. ► Acute cognitive impacts (usually due to pain) include reduced concentration and information processing, and subsequent reduction in hazard detection and response capabilities. ► Chronic cognitive impacts typically present as mental health illnesses such as anxiety and depression.
What we know about the risk (available data and evidence from RSHQ and elsewhere)
Lost time injury (LTI) data from the mining sectors indicated that 27% (911 reports) of all LTIs reported to RSHQ between 2011 and 2020 involved an MSD [1]; of these LTIs, 98% were temporarily disabling. This suggests that most reported MSDs are not severe enough to result in an injury so significant that it would prevent a return to work. RSHQ LTI data indicated that LTIs caused by MSDs primarily presented in the mining sector. Coal was more heavily represented in the data than other mine types. The top departments attributed to MSD-related LTIs were 'production' (59%); 'mechanical' (17%), and 'unspecified' (12%). The top 'worksite location' classifications associated with LTIs caused by MSD were 'open cut pit/ excavation mining' (11%), 'other surface location' (7%) and 'overburden removal' (6%). LTI data was not available for the petroleum and gas or explosives sectors. Accepted workers' compensation claim data from 2016-2021 was reviewed [2]; while this document was titled as claims for the mining sector, it included claims data from other sectors as well. This analysis also indicated that 85% of all MSD related claims were from injuries in surface mining. However, per capita, underground miners were 50% more likely to sustain an MSD compared to surface miners. Similarly, MSDs that gave rise to a workers' compensation claim in Queensland resources were predominantly from the mining sector. 56% of workers' compensation claims lodged between July 2016 and December 2020 were related to an MSD. [2] Of these claims, 30% were related to copper mining underground, 21% were related to open cut coal mining, and 10% were related to underground coal mining. Agency and mechanism data were not sufficiently detailed to allow for meaningful insight on which occupations or tasks may benefit from increased focus from a manual task risk management perspective.

Accepted workers' compensation claim data [2] provides classification of each claim by diagnosis, as well as a highly generic description of the mechanism of injury. Drawing conclusions from either of these data sets is problematic, owing to the vagueness and variability of classification assignment to individual claims. It is also too vague to allow a more targeted evaluation of which roles, tasks, or pieces of equipment may be significant contributors to MSDs in each sector.

An analysis of accepted MSD claims data in the resources industry in Western Australia [3] indicated that, in a review of 3 years of workers' compensation data, 67% of claims resulting in an MSD involved more than 14 lost work days and were considered 'serious' according to the Department of Mines and Petroleum. This figure increased to 90% when recurring injuries were analysed.

To summarise findings by sector:

- Across coal, mining, and quarrying— the three sectors for which LTI data is available—MSDs were the top cause of LTIs
- MSDs were the leading contributor to accepted workers' compensation claims across all sectors

For all sectors, it is unclear which occupations or tasks are the most likely driver of MSDs, where MSD-related LTIs were reported, as occupation or task risk data that would allow this analysis was not available. This is complicated by evidence which suggests that MSDs are cumulative in nature, and there is no available data describing the exposure to cumulative MSD risk within any sector.

How we can learn more about the impact of this risk in the resources sector in Queensland

To provide a meaningful snapshot of the current state of MSD risk, an analysis of injury and claim data should be conducted which incorporates occupation data, task/s associated with injury, and potentially, time in role. This time in role data will provide insight into the relationships (if any) between duration of exposure and task experience, and the likelihood of developing an MSD.

The risk factors discussed in this chapter—those that can give rise to an MSD—can be assessed using tools described further in this chapter. RSHQ could use these tools as part of a targeted risk assessment approach, to better quantify these risks. This will allow for prioritisation of these risks relative to other health risks, as well as determine their significance within each industry sector in RSHQ's remit.

Proactively identifying manual task risk though assessment of the tasks themselves would enable targeted control of the factors most likely to contribute to MSDs. Completing assessments of the same tasks at a suitable interval would also allow for better assurance of the effectiveness of control measures for those tasks deemed to most substantially contribute to MSD risk.

Given the significant contribution that MSDs make to workers' compensation claims in quarrying, petroleum and gas, and explosives, this system of targeted assessments (and possible subsequent targeted interventions) has potential to deliver a measurable return on investment, depending on average cost of claim in these sectors. Cost of claim data was not available to determine whether this would be the case.

RSHQ should determine whether this data can be obtained from industry, or collected by the inspectorates, consistent with the overall comments this report makes regarding targeted assessments.

13.2 What is the health hazard and consequences of exposure?

13.2.1 What is an MSD?

MSDs include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves and supporting blood vessels.[4] MSDs are typically multifactorial in their aetiology and encompass a wide range of clinical diagnoses, including ‘sprains and strains’, ‘repetitive strain injuries’, ‘tendinitis’, ‘sciatica’, and ‘back pain’, among others.

MSDs are usually diagnosed based on presentation of symptoms and a clinical assessment, as well as imaging studies in some cases. Definitively diagnosing these injuries is problematic, with poor reliability between clinicians for ascribing an International Classifications of Diseases (ICD) diagnosis.[5] Additionally, the disease codes used to classify MSDs are varied, which presents a challenge for the coding and classification of data, and the subsequent analysis of lagging indicator data for risk management purposes. [6]

Symptoms of an MSD can include:

- Localised or generalised aching, pain, and discomfort
- Loss of sensation, or hypersensitivity to heat, touch, and pressure
- Loss of muscle strength, endurance, or flexibility
- Loss of ability to perform controlled movements, balance, or postural reactions
- Abnormal alignment of joints, loss of joint range of motion or stability
- Physical changes to muscle tone or bulk [6]

Sustaining an MSD increases the likelihood that an individual will experience an MSD again in the future. Individuals experiencing an MSD, particularly a work-related MSD, often face functional capacity limitations which inhibit their ability to perform physical tasks at work by way of pain and/or limited range of motion. This results in movement compensations which increase the likelihood of a new MSD. [6]

Acute cognitive impacts are more likely when working with an MSD. These impacts include reduced concentration and information processing capacity due to pain. These symptoms are also associated with psychological stress, which can further undermine performance at work. This reduced cognitive capacity can reduce an individual’s ability to detect and respond to safety hazards, increasing the likelihood of being involved in a serious and possibly fatal incident.[6]

Experiencing symptoms of an MSD, particularly pain, increases the likelihood that a worker will be diagnosed with a mental health illness such as anxiety or depression, and this has been evidenced within the coal mining workforce, particularly for equipment operators.[5]

13.2.2 How does an MSD develop?

MSDs can arise from a single exposure to a high force, or a strenuous activity, but more commonly arise from cumulative exposure to the same hazards for an extended period. This cumulative exposure can eventually result in sufficient damage to soft tissues such that symptoms of an MSD eventuate.[7] This cumulative nature poses a challenge for the ergonomics professional and treating practitioner alike, in that it is difficult to ascribe the cause of an MSD to a single task or piece of equipment. The cause of an MSD needs to be considered in the context of an employee's entire job design.[7]

MSDs can be considered 'acute', or 'chronic', although the distinction between the two diagnoses is somewhat arbitrary.[8] Prolonged, repeated exposure to risk factors that give rise to an MSD is more likely to leave the injured person with persistent symptoms and related loss of functional capacity, with reduced chances of recovery.

The likelihood of developing an MSD because of exposure to these risk factors is dose dependent. That is, MSDs are more likely with increased frequency, duration, and magnitude of exposure to these risk factors, and the greater the number of risk factors present, the greater the likelihood that an MSD will result from exposure.[7] While tasks involving exposure to MSD risk have previously been described as 'manual handling' tasks, not all tasks involve handling a physical item, and so the preferred term is now 'manual task'.

13.2.3 Risk factors that give rise to an MSD: physical risk factors

'Manual tasks' can involve exposure to the following MSD risk factors [7]:

Forces: Any element of the task that involves bringing motion to bear on an object. While this is commonly thought of as lifting objects, it can also involve lowering, pushing, pulling, and sliding. The weight of the object itself is a contributor to this risk factor, as well as the size of the object, and distance the object is positioned from the body. Other influencing factors include the speed of manipulation and rate of object acceleration and deceleration, as well as the amount of force generated proportional to the size of the muscle group generating the force.

Figure 17: Force is required to use the hammer. [9]

Repetition: If the task involves repeated performance of identical patterns of movement, and especially if the cycle time of the repeated movement is short, then the same tissues are being loaded in the same way with little opportunity for recovery. Such repetitive tasks are likely to pose a high risk of cumulative injury if combined with moderate-to-high forces (or speeds), awkward postures and/or long durations.

Figure 18: Repetition combines with awkward postures to amplify risk exposure. [9]

Awkward postures: Muscle tissue exhibits a length-tension relationship and can generate maximum force when joints are positioned in a way that optimally exploits the length-tension relationship of muscles around that joint. The further a joint is positioned from anatomically neutral, the greater the chance that the muscles around the joint will not be able to generate enough force to maintain the posture or perform the desired task efficiently at those extremes of posture.

Combining high forces, significant repetition, or prolonged sustained postures with work in an awkward posture increases injury risk.

Figure 19: Awkward posture is required to access conveyor rollers. [9]

Sustained postures: The optimal design of work provides tasks involving slow-to-moderately paced movements and varied patterns of movement. Little or no movement at a body part elevates the risk of discomfort and injury because the flow of blood through muscles to provide energy and remove waste depends on movement. Tasks involving static postures quickly lead to discomfort, especially if combined with exposure to other risk factors.

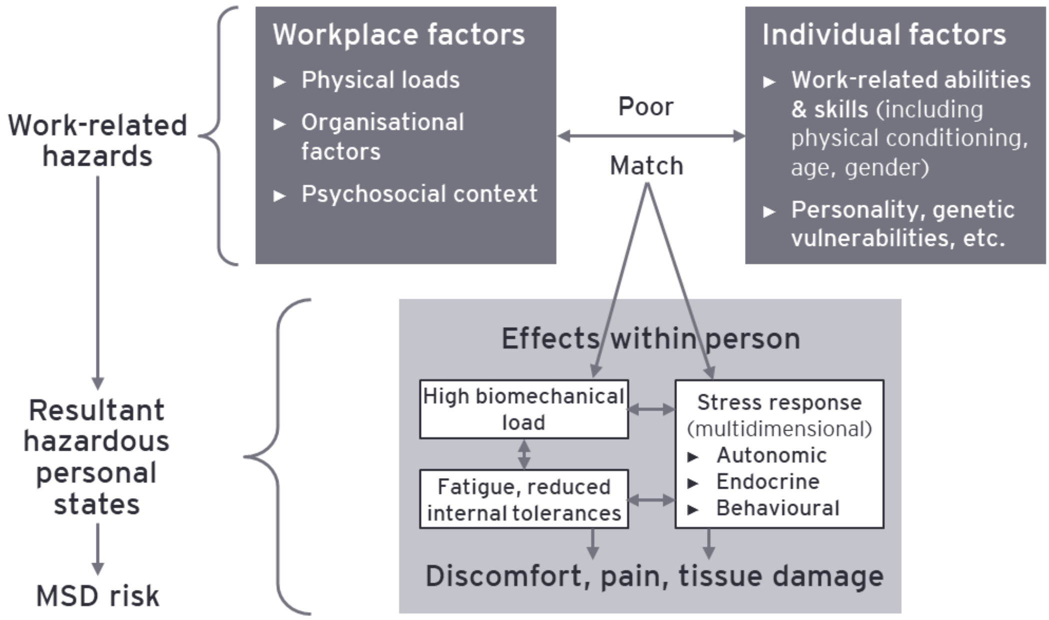
Figure 20: Sustained postures are used to complete this welding task. [9]

Vibration (whole body and/or hand-arm): This is discussed in detail in chapters 9 and 21 of this report. Exposure to vibration has an amplifying effect when combined with the above risk factors.

13.2.4 Risk factors that give rise to an MSD: organisational and psychosocial risk factors

These 'physical' risk factors are further compounded by organisational and individual factors that further limit the individual's capacity to work, and therefore increase the likelihood they will develop an MSD.

Figure 21: The relationship between MSD risk factors and the effects on an individual. Source: [5]



Organisational psychosocial risk factors are explored further in chapter 12 and include long working hours, low job control, high pace of work, relationships with managers, supervisors, and peers, and conflicting job demands. Exposure to these risk factors is known to amplify the effects of exposure to physical risk factors, increasing the likelihood of an injury developing, and also increasing the risk of developing a chronic MSD. [8]

Individual psychosocial risk factors are also explored in chapter 12 and include reduced tolerance to stress, and pre-existing psychological illness such as anxiety or depression. Exposure to these risk factors in combination with exposure to physical, task-related risk factors can also have an amplifying effect and increase the likelihood of developing a chronic condition. [10]

13.3 Who is exposed? And how are they exposed?

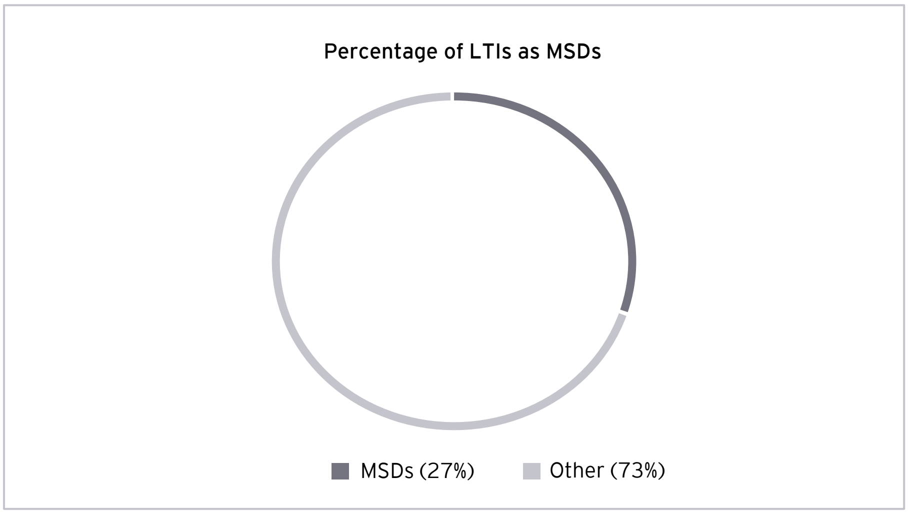
It is difficult to single out any one group of employees or workplace type as being at higher risk of MSDs than others. Any worker in the resources sector can ultimately be exposed to the previously described risk factors that contribute to MSDs, by virtue of performing manual tasks in the work environment. These manual tasks can range from operating a computer workstation, through to operating a heavy vehicle or performing maintenance tasks in a workshop.

As with other occupational health risks, a hazard identification, assessment, and control approach, supported by controls monitoring, is the ideal framework for preventing health effects in workers. The ultimate aim of manual-task risk management is to ensure that all tasks performed in workplaces require dynamic and varied movements of all body regions with low-to-moderate levels of force, comfortable and varied postures, no exposure to whole-body or peripheral vibration, and that breaks are taken at appropriate intervals to allow adequate recovery. Injuries are more likely when there are deviations from this optimal situation, and injuries are most likely to occur when there is significant exposure to multiple risk factors. [7].

13.3.1 Mining sector lost time injury data

LTI data for the mining sector indicated that 27% (911 reports) of all LTIs reported to RSHQ between 2011 and 2020 involved an MSD [1]; 'human error' is the second most prevalent classification, however this classification does not provide an indication of the diagnosis of the type of injury that resulted in lost work time. Days lost ranged between 1 and 461, with an average of 36 days lost across all LTIs reported.

Figure 22: Percentage of all LTIs that were MSDs.



The top contributing sectors were open cut coal and copper mining:

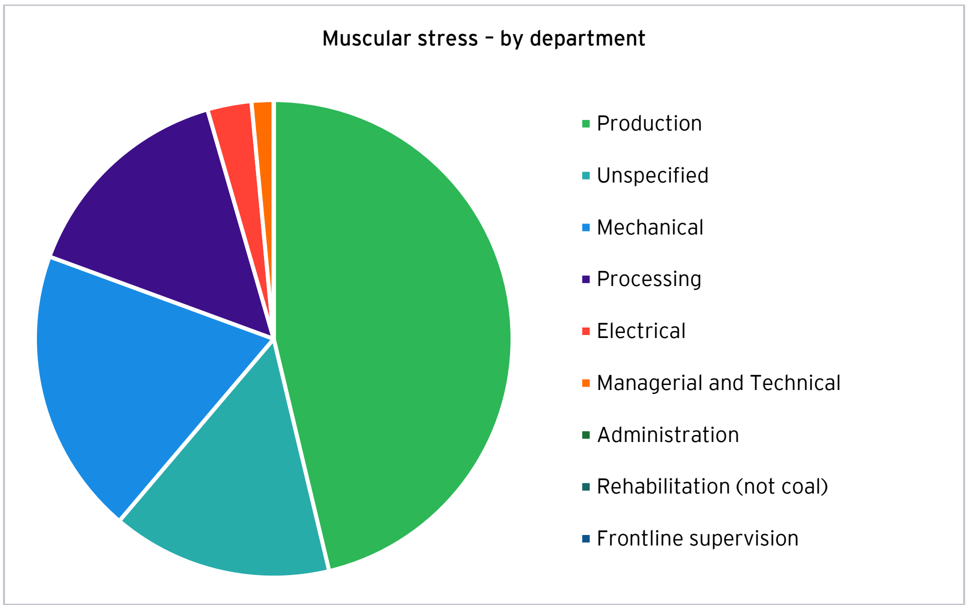
Table 18: Contributing sectors to MSDs

Resource type	Percentage
Coal exploration	0.38%
Coal open cut	8.32%
Coal underground	6.60%
Mining exploration	0.17%
Mining open cut	2.62%
Mining other	0.06%
Mineral quarries	1.19%
Mining underground	1.66%
Other	6.00%
Grand total	**27.00%**

Of these LTIs, 98% were temporarily disabling—only 2% of LTIs resulted in the injured worker being unable to return to work.

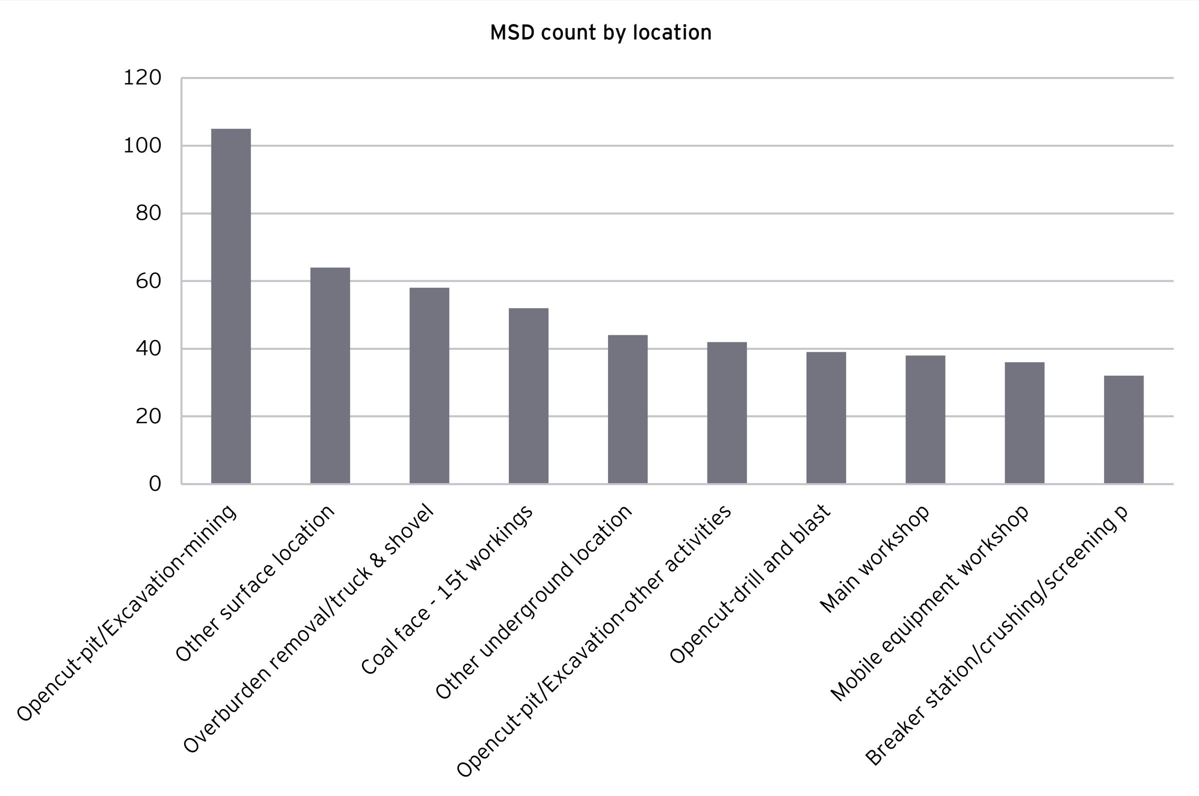
Analysis of data across all mining sectors indicated that the top departments attributed to MSD-related LTIs were 'production' (59%); 'mechanical' (17%), and 'unspecified' (12%).

Figure 23: Muscular stress injuries by department



The top 'worksite location' classifications associated with LTIs caused by MSD were 'open cut pit/ excavation mining' (11%), 'other surface location' (7%) and 'overburden removal' (6%).

Figure 24: MSD count by location



LTI data was not provided for the petroleum and gas or the explosives sector.

13.3.2 Review of RSHQ workers' compensation data

56% of workers' compensation claims accepted between 2016 and 2021 were related to an MSD. [2] Of these claims:

- 30% were related to copper mining underground
- 21% were related to open cut coal mining
- 10% were related to underground coal mining

The table below outlines the rate of MSD claims in other industries/ sectors included in the data.

The remaining industries/ commodity types represented low percentages of the total claims lodged. By comparison, deafness was the second largest contributor to workers' compensation claims, in comparison, representing 25% of all accepted claims.

Table 19: MSD claims by resource type

Resource Type	Percentage
Bauxite Mining Open Cut	3%
Coal Mining Open Cut	21%
Coal Mining Underground	10%
Copper Ore Mining Open Cut	2%

Resource Type	Percentage
Copper Ore Mining Underground	30%
Drilling and Boring Support Services	4%
Explosives Manufacturing	2%
Gas Supply	2%
Gold Ore Mining Open Cut	1%
Gold Ore Mining Underground	1%
Gravel and Sand Quarrying	2%
Mineral Exploration (Own Account)	0%
Mineral Exploration Services	1%
Mineral Sand Mining	0%
Oil and Gas Extraction	1%
Other Construction Material Mining	5%
Other Mining Open Cut	2%
Other Mining Support Services	7%
Other Petroleum and Coal Product Manufacturing	0%
Petroleum Exploration (Own Account)	0%
Petroleum Exploration Services	0%
Petroleum Refining and Petroleum Fuel Manufacturing	2%
Silver-Lead-Zinc Ore Mining Underground	2%
Grand Total	100.00%

By comparison, LTI data [1] indicated that open cut coal mining was a significant contributor to LTIs:

Table 20: MSD LTIs by mine type

Mine type	Percentage
Coal – open cut	51.92%
Coal - underground	22.83%
Mining – open cut	13.17%
Mining - underground	5.60%
Quarrying	4.94%
Coal exploration	0.77%
Mining exploration	0.55%
Mining - other	6.22%
Grand total	**100.00%**

This data, however, may not necessarily be indicative of the prevalence of MSDs in each sector, and may instead be an indication of the effectiveness of medical case management practices in the other sectors in comparison to open cut coal mining. The analysis of workers' compensation data also suggests that some sectors may be underreporting LTIs, or aggressively case managing MSDs which require medical treatment, and thus injured workers in these sectors do not lose any work time because of their injury.

An analysis of the 'equipment' subset of LTI data [1] highlights the difficulty in attributing any one specific task or piece of equipment to disorders that are typically cumulative in nature. The following table outlines which pieces of equipment were attributed to LTI reports, with the majority being 'no equipment involved'. This presents difficulty in attributing which tasks or pieces of equipment may be contributing most to MSDs, and which tasks or equipment might be best for focus as part of a targeted risk assessment initiative.

Table 21: MSD LTIs by equipment type

Equipment type	Percentage
No equipment involved	17.89%
Other non-powered equipment / Object	9.98%
Dump truck - rear	8.40%
Unspecified / unknown equipment	5.24%
Dozer - tracked	5.04%
Non-powered hand tool	5.04%
Other vehicle (5T Gross or Less) - surface	2.87%
Hose	2.67%
Other vehicle (> 5T Gross) - surface	2.47%

It appears that the Mining division were the only sector who would code LTIs to include data on which body part was injured. This data is also problematic in that exposure to MSD risk factors can result in symptoms of an MSD developing in different areas of the body for different individuals. This makes it difficult to assume a relationship between which tasks or equipment may be driving the development of MSDs, purely based on affected body part data alone.

13.3.3 Workers' compensation data: Queensland resources sector analysis

The accepted claims data [2] provided does not include details about the tasks or occupations that were specifically implicated in the injuries associated with MSD claims. Mechanism of injury data suggests that tasks involving lifting and carrying objects may be more frequently associated with an MSD claim [2]. However, using this data as the basis of a targeted assessment is problematic, owing to the lack of specificity in categorisation, and the cumulative nature of MSDs.

Table 22: MSD claims by mechanism of injury

Mechanisms of injury	Percentage
Being hit by falling objects	1%
Being hit by moving objects	1%
Muscular stress while handling objects other than lifting, carrying, or putting down	47%
Muscular stress while lifting, carrying, or putting down objects	21%
Muscular stress with no objects being handled	10%
Other and multiple mechanisms of incident	11%
Repetitive movement, low muscle loading	0%
Stepping, kneeling, or sitting on objects	0%
Unspecified mechanisms of incident	8%
Being hit by falling objects	1%
Grand total	**100.00%**

Agency and mechanism data were not sufficiently detailed to allow for meaningful insight on which occupations or tasks may benefit from increased focus from a manual task risk management perspective. Agency information was nonspecific, with 25% of MSD claims classified as 'agency not apparent', and the remainder of claims very widely dispersed over the remaining agency classifications.

Additionally, MSDs represent a material contributor to the number of workers' compensation claims accepted in each sector, as well as overall:

Table 23: MSD claims by resource type

Resource Type	Deafness	Diseases of Musculoskeletal System	Mesothelioma/ Asbestosis	Other Diseases	Psychiatric/ Psychological Injury
Bauxite mining open cut	12.82%	66.67%	0.00%	17.95%	2.56%
Bauxite mining underground	100.00%	0.00%	0.00%	0.00%	0.00%
Coal mining open cut	43.34%	35.31%	0.33%	12.76%	8.25%
Coal mining underground	26.74%	43.90%	0.00%	23.26%	6.10%
Copper ore mining open cut	5.00%	85.00%	0.00%	5.00%	5.00%
Copper ore mining underground	16.47%	74.45%	0.17%	7.73%	1.18%
Drilling and boring support services	2.27%	73.86%	0.00%	19.32%	4.55%
Explosives manufacturing	15.38%	64.10%	2.56%	12.82%	5.13%
Gas supply	0.00%	75.00%	3.13%	21.88%	0.00%
Gold ore mining open cut	7.69%	69.23%	0.00%	7.69%	15.38%
Gold ore mining underground	18.75%	75.00%	0.00%	6.25%	0.00%
Gravel and sand quarrying	6.98%	81.40%	0.00%	6.98%	4.65%
Iron ore open cut	0.00%	0.00%	0.00%	100.00%	0.00%
Metal ore mining N.E.C. Open cut	75.00%	0.00%	0.00%	25.00%	0.00%
Mineral exploration (own account)	16.67%	58.33%	0.00%	16.67%	8.33%
Mineral exploration services	19.35%	67.74%	0.00%	9.68%	3.23%
Mineral sand mining	42.86%	28.57%	0.00%	0.00%	28.57%
Oil and gas extraction	8.33%	66.67%	0.00%	16.67%	8.33%
Other construction material mining	14.74%	74.74%	0.00%	10.53%	0.00%
Other mining open cut	17.31%	50.00%	0.00%	15.38%	17.31%
Other mining support services	8.81%	65.41%	0.00%	21.38%	4.40%
Other mining underground	100.00%	0.00%	0.00%	0.00%	0.00%
Other petroleum and coal product manufacturing	11.11%	66.67%	0.00%	22.22%	0.00%
Petroleum exploration (own account)	50.00%	16.67%	0.00%	33.33%	0.00%
Petroleum exploration services	0.00%	69.23%	0.00%	15.38%	15.38%
Petroleum refining and petroleum fuel manufacturing	18.42%	65.79%	0.00%	7.89%	7.89%
Silver-lead-zinc ore mining open cut	100.00%	0.00%	0.00%	0.00%	0.00%

Resource Type	Deafness	Diseases of Musculoskeletal System	Mesothelioma/ Asbestosis	Other Diseases	Psychiatric/ Psychological Injury
Silver-lead-zinc ore mining underground	5.56%	86.11%	0.00%	5.56%	2.78%
Grand total	**25.42%**	**55.36%**	**0.22%**	**13.60%**	**5.40%**

The data provided by RSHQ did not allow for an analysis of LTIs or workers' compensation claims by task associated with injury, nor did it allow for analysis by occupation. The data did not appear to include any LTI reports that could be attributed to the Petroleum and Gas or Explosives industries; though it should also be noted that almost 4.5% of MSD related workers' compensation claims arose from the petroleum and gas industries.

13.3.4 Summary of data by sector

Mining: MSDs in the mineral mining sector represented 4.5% of all mining sector LTIs reported to RSHQ.

- 48% of all accepted MSD related workers' compensation claims arose from the mining sector
- MSDs in mining represented 25.6% of all workers' compensation claims and 39% of workers' compensation claims overall
- While MSDs in mining did not significantly contribute to LTIs, they represent a significant contribution to workers' compensation claim numbers and likely costs as well

Coal: Within the sector, MSDs are a significant driver of LTIs and workers' compensation claims.

- LTIs caused by MSDs represented 15.3% of all coal sector LTIs reported to RSHQ
- 17.4% of all workers' compensation claims in coal related to MSDs
- By comparison, coal represented 46.3% of workers' compensation claims overall
- Within coal, MSDs are on par with deafness for contribution to workers' compensation claims in the sector

Quarrying: MSDs in quarrying represented 1.2% of LTIs overall.

- They represented 81% of all workers' compensation claims for the sector
- This suggests there may be underreporting of MSD related LTIs in the sector, given the substantial contribution they make to workers' compensation claims for the sector

Petroleum and Gas (P&G): Petroleum and gas were not represented in LTI data

- However, of all workers' compensation claims lodged for the sector, 66% of claims related to diseases of the musculoskeletal system, or MSDs
- This suggests that workers in P&G are likely significantly exposed to MSD risk factors to an extent they give rise to compensable injuries

Explosives: The explosives sector was not represented in LTI data.

- However, of all workers' compensation claims lodged for the sector, 64% of claims related to diseases of the musculoskeletal system, or MSDs
- This suggests that workers in explosives are likely significantly exposed to MSD risk factors to an extent they give rise to compensable injuries

13.3.5 By comparison: workers' compensation claims lodged in resources in Western Australia

An analysis of MSD injury data in the resources industry in Western Australia [3] indicated that, in a review of 3 years of workers' compensation data, 67% of claims resulting in an MSD involved more than 14 lost work days and were considered 'serious' according to the Department of Mines and Petroleum. This figure increased to 90% when recurring injuries were analysed. The number of claims in WA are higher than the figures represented in RSHQ workers' compensation data, although recurring claim data was not available for Queensland.

This analysis also indicated that 85% of all MSD related claims were from injuries in surface mining, however, per capita, underground miners were 50% more likely to sustain an MSD compared to surface miners. RSHQ data did not permit the same per capita analysis to determine the prevalence of injuries in surface operations versus underground operations.

This Western Australian data [3] analysis indicated the following breakdown of MSD-related injuries by the following locations. This contrasts with RSHQ's data, where LTIs were predominantly sustained in the pit and other surface locations.

Table 24: Western Australian MSD LTI data

Treatment plant / ore processing	47%
TP: Process plant other	17%
TP: Crushing / screening / conveyor	7%
TP: Leaching	6%
TP: Filters / presses / wet screening	6%
TP: Crystallisation / nucleation / ion exchange	5%
TP: Grinding / classification	4%
TP: Crushed ore areas	2%
Open pit production / development areas	15%
OP: Bench area	7%
OP: Face loading area	4%
OP: Haul road	2%
OP: Other	2%
Surface work areas general	14%
S: Warehouse / stores / rebuild area	5%
S: Other	5%
S: Laboratory	4%
Workshop surface	13%
WS: Heavy equipment	7%
WS: Other	6%

Administration	9%
Power generation plant	1%
Railways	1%

Injuries in underground work areas were broken down as follows:

Table 25: MSD LTIs in underground work areas

Underground production / development areas	72%
Level development	32%
Stope	12%
Decline / winze development	12%
Capital development	11%
Raise development	5%
Access / traveling / haulage ways	14%
Decline / audit / drift	8%
Haul road / level	6%
Not stated	5%
Storage	3%
Ore / waste dumping	3%
Workshop	3%
Pump chamber	1%
Crushing	1%
Ancillary locations	1%

Injuries were also broken down by occupation:

"Processing Plant Operators accounted for 26% of all manual task injuries and Fitters/Boilermakers accounted for 18%. If surface and underground Mobile Plant Operators were placed in the same occupational category, they became the third highest risk occupation, accounting for nine percent of all manual task injuries." [3]

Occupation data for Queensland was not available for a comparison.

13.3.6 A summary of overall claims data in Australia

An analysis of all MSD claims in Australia [6] indicated that 65.7% of all serious claims in mining, and 62% of all gas sector serious claims, resulted from an MSD. This is compared to 58.1% of all serious claims lodged across all industries in Australia.

Claims data for Queensland could not be broken down by severity to allow a comparison, and as such, these aggregated statistics should be considered indicative of the current prevalence of serious claims in resources in Queensland.

13.4 What are the current Queensland regulatory requirements for the management of the hazard?

The Coal Mining Safety and Health Regulation (2017) includes general clauses about workers' fitness for work but does not provide specification around the application of these clauses to the prevention of MSDs.

Part 11 of the Regulation includes a specification to provide workers with manual handling training, however, does not specify what content should be covered in said training. Systematic reviews of evidence, however, indicate that 'manual handling' training is no more effective at preventing MSDs than providing no intervention. [11] Part 96 requires mines to have an SOP (presumably at least a generic SOP) which addresses how manual task risks will be minimised.

The Mining and Quarrying Safety and Health Regulation (2017) [12] requires employers to select and design plant which is ergonomically compatible for operators and maintenance staff. General consensus among ergonomists and engineers [13] is that designing out MSD risk, in line with this regulatory approach, is more effective than the administrative control based focus taken in the *Coal Mining Safety and Health Regulation*.

The Hazardous Manual Tasks Code of Practice (2021), published by Workplace Health and Safety Queensland [14] provides guidance on the identification, assessment, control, and monitoring of manual task risk, and, consistent with current evidence, specifies that 'lifting technique' training is not an effective control to reduce the risk of an MSD. [15]

The Petroleum and Gas (Safety) Regulations do not provide any specifications for the management of MSD risk. Nor does the *Explosives Act* or Regulations.

13.5 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

The Australian Work Health and Safety Strategy 2012-2022 [16] had three key aims, one of which was to reduce the incidence of MSDs in Australia requiring one or more weeks off work by 30%. One pillar of the strategy was the elimination of hazards which may cause MSDs by designing them out. State-based regulators, including Workplace Health and Safety Queensland, have taken a similar approach to managing manual task risk, promoting the application of the hierarchy of control in reducing manual task risk exposure. [17]

The NSW Resources Regulator does not make any specifications in the Act or Regulations for the identification, assessment, or control of risks that may result in an MSD. The guidance note 'Managing musculoskeletal disorders' provides information on the management of MSD risk factors in the mining industry. [18]

The NSW approach is consistent with the prevention strategy published by Safe Work Australia [16], which promotes using the hierarchy of controls to design out manual task risk where practical to do so. Additionally, the NSW Resources Regulator heavily promotes the development of ergonomic technical capability within the resources sector workforce, as well as the advocacy for a participatory ergonomics framework. Their focus is on prevention through design rather than medical surveillance and injury case management.

The Western Australian Department of Mines and Petroleum (DMP) does not specifically regulate the identification, assessment, or control of risks that may result in an MSD. They have produced a series of fact sheets to aid employers in this process, including information on how to develop and implement a participatory ergonomics framework. [19]

Various peer reviewed journal articles are available, along with guidance notes prepared by the regulators, that outline risk factors and control measures associated with the management of task-specific MSD risks in the resources sector. The style of guidance and preventative approach taken by the NSW Resources Regulator appears particularly worthy of emulation, especially since the guidance they provide is tailored specifically to the resources sector. By comparison, the guidance material provided by state-based regulators such as Workplace Health and Safety Queensland, is, by necessity, more general in nature and does not provide the same specifics in application.

13.6 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

The multifactorial nature of MSD risk means there is no one single value-based exposure threshold, or standard, at which exposure to the risk becomes acceptable. Commonly used risk assessment tools consider the impact of magnitude, frequency, and duration of exposure. Assessing the overall risk exposure to an individual is complicated by the impact of cumulative task risk (that is, the amplifying or dampening effect caused by risk exposure across multiple tasks) and individual health factors.

13.7 How is the hazard measured/evaluated in the workplace?

RSHQ currently does not use any risk assessment tools to quantify exposure to risk factors which may give rise to musculoskeletal disease.

The Queensland Hazardous Manual Tasks Code of Practice (2021) [14] provides a risk assessment worksheet which enables hazard identification and qualitative risk assessment of those hazards. The Code of Practice also recommends a number of risk assessment tools that can be used for semi quantitative measurement of manual task risk:

Table 26: Recommended ergonomic assessment tools from the Queensland Hazardous Manual Tasks Code of Practice

Method	More information
3D Static Strength Prediction Program™ (computer software)	University of Michigan Center of Ergonomics https://c4e.engin.umich.edu/tools-services/3dsspp-software/ Relevant for slow movement only.
Rapid Entire Body Assessment (REBA)	Hignett, S, McAtamney, L. 2000. 'Rapid Entire Body Assessment (REBA)'. *Applied Ergonomics* 31: 201-205. Middlesworth, M. *Rapid Entire Body Assessment (REBA): A step-by-step guide*. https://ergo-plus.com/reba-software/
Posture, Activity, Tools, Handling (PATH)	Buchholz, B, Paquet, V, Punnett, L, Lee, D, Moir, S. 'PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work'. 1996. Applied Ergonomics 27, no. 3: 177-87. https://www.sciencedirect.com/science/article/pii/000368709500078X
Manual Tasks Risk Assessment Tool (ManTRA)	University of Queensland, Workplace Health and Safety Queensland, Curtin University of Technology. https://www.worksafe.qld.gov.au/injury-prevention-safety/hazardous-manual-tasks/mantra
Participative Ergonomics for Manual Tasks - PerforM	WorkCover Queensland https://www.worksafe.qld.gov.au/injury-prevention-safety/hazardous-manual-tasks/participative-ergonomics-for-manual-tasks-perform
OCRA System	Colombini, D, Occhipinti, E, Grieco, A. (2013). *The revised OCRA checklist method*. Editorial Factors Humans. http://www.ergonomiesite.be/documenten/repetitief/Revised-OCRA-Checklist-Book.pdf

Method	More information
The Work Organisation Assessment Questionnaire (WOAQ)	EEF. (2004). Work Organisation Assessment Questionnaire: A tool for the risk management of stress. London: EEF. https://oem.bmi.com/content/63/10/669
Hazardous Manual Tasks Risk Management Worksheet	WorkCover Queensland https://www.worksafe.qld.gov.au/injury-prevention-safety/hazardous-manual-tasks/identifying-and-assessing-hazardous-manual-tasks

The ergonomics research community continues to build and test additional cumulative risk assessment tools. These tools are designed to quantify the degree of MSD risk a worker is exposed to over the duration of a work shift, and sometimes longer. Examples of these risk assessment tools include the Occupational Repetitive Actions assessment tool (OCRA). However, the majority of validated assessment tools focus on quantifying the degree of ergonomic risk associated with a single task in isolation. [20]

The availability of technology for the collection of quantifiable data is also improving. Where electromyography (EMG) was previously the preferred method for collecting effort related data, less intrusive and more powerful data collection and assessment technologies are now available for those situations where a detailed, data rich task analysis is warranted. These include smart watch type devices, wearable joint position and motion sensors, software which scans and analyses worker movement, and other emerging technologies. [21, 22]

13.8 What health surveillance data is currently available to RSHQ?

The data available from RSHQ at present is predominantly workers' compensation and LTI data. Because this is lagging indicator data in response to very significant injuries and/or workers' compensation claims, the data does not represent the full extent of risk exposure and subsequent exposure outcomes in the Queensland resources sector. MSDs that required medical treatment are not represented in the provided data and are likely more numerous than LTIs and/or workers' compensation claims.

The Coal Mine Workers' Health Scheme collects some basic musculoskeletal function data, including gross range of motion, reflexes, gait, and straight leg raise. This could potentially be cross referenced with position title data, to indicate which populations may be more at risk of an MSD. However, this exercise would not be as insightful as the analysis of data collected based on task risk exposure if the intention of the data collection work is to aid the prevention of MSDs.

The NSW Resources Regulator requires health surveillance be performed for coal mine workers. [23] A 'general musculoskeletal assessment' is required as part of this health surveillance, in a manner not dissimilar to the Coal Mine Workers' Health Scheme in Queensland. Again, this has extremely limited value as a preventative measure, as the time between medicals spans a number of years, and any MSDs detected under such a scheme are likely to have become chronic in nature, leading to poorer recovery outcomes.

RSHQ data, despite its limitations, is consistent with the analysis of Western Australian workers' compensation data [3] and associated data, both of which suggest that MSDs represent a significant proportion of compensable injuries in the resources sector.

This Western Australian [3] data provides the best indication of which occupations are likely most affected by MSDs within the mining sector, i.e., processing plant operators, fitters/boilermakers and mobile plant operators. Data is not available by occupation for the highest MSD rates in other sectors such as petroleum or explosives.

To provide a meaningful snapshot of the current state of MSD risk, an analysis of injury and claim data should be conducted which incorporates occupation data, task/s associated with injury, recurring claims, and potentially, time in role. Given this information was not provided as part of the supplied LTI or workers' compensation data sets, it is recommended this data be collected in future to aid a richer analysis.

Promotion of a prevention-through-design framework, combined with a participatory ergonomics approach, is the most proactive method of identifying, assessing, controlling, and monitoring the risk factors that give rise to MSDs. Provision of guidance and support to resources sector organisations to take this approach, with sector specific guidance where possible, provides the best likelihood of realising this approach in a way that delivers best outcomes for resources sector employees.

Ideally, health risk assessments and/or targeted reviews should incorporate a semi-quantitative risk assessment of higher risk tasks, using the tools identified in this chapter of this review. Proactively identifying manual task risk though assessment of the tasks themselves would allow for targeted control of the factors most likely to contribute to MSDs. Completing assessments of the same tasks at a suitable interval would also allow for better assurance of the effectiveness of control measures for those tasks deemed to contribute to MSD risk most substantially.

13.9 References:

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Nanotech (emerging risk)

14. Nanotech (emerging risk)

14.1 Overview

Summary of the health effects presented by the risk
There is currently insufficient scientific evidence to determine whether engineered nanomaterials (ENM), as a collective, are benign or harmful to workers' health. This is a developing area of research and current knowledge suggests that there may be some potential for adverse health impacts from certain types of ENMs, including potential for fibrogenic health effects from inhaled nano-fibres and nanoparticles. There is evidence from *in vitro* and *in vivo* studies of oxidative stress and increased inflammatory markers in various cell types. Risk assessment of exposures in the workplace is challenged by a lack of epidemiological data, insufficient toxicological and physical risk information, and limited monitoring data.
What we know about the risk (available data and evidence from RSHQ and other sources)
Resource sector workers are not involved in the manufacture of ENMs, which creates the highest exposure risk, but are potentially exposed from the use of ENMs within the resource sector (such as the use of sunscreen, among other things discussed in this chapter in section 1.4). Use of nanotechnology in the resource sector is growing. There is currently no published quantitative ENM exposure data for the resource sector and no data could be provided by RSHQ as part of this review. Very little is known about potential ENM exposures in the resource sector.
How we can learn more about the impact of this risk in the resources sector in Queensland
It is recommended that RSHQ monitor: ► The growth in use of ENMs in the resource sector ► The emerging scientific literature on potential adverse health effects from ENM exposures RSHQ should work together with the federal regulatory bodies, including the Australian Industrial Chemicals Introduction Scheme (AICIS) and the Therapeutic Goods Administration (TGA), to ensure that appropriate regulatory steps are taken to ensure any unacceptable risk of harm to workers in the resource sector from ENMs is identified and managed. Where ENMs are in use, the hierarchy of control measures should be applied to ensure workers' health is protected. Given the gaps in scientific knowledge, the risks from exposure should not be underestimated. Control banding techniques can be applied to assist with the risk management process.

14.2 What is the health hazard?

The hazard is the potential for exposure to nanomaterials through inhalation, the dermal route, or via the digestive system. Nanomaterial is defined as:

> *"Material with any external dimension in the nanoscale or having internal structure or surface structure in the nanoscale."*[1]

The Australian Industrial Chemicals Introduction Scheme (AICIS) (formally known as NICNAS) define nanoscale as a particle in the size range of 1 to 100nm[2]. AICIS deem a chemical as being in the nanoscale *"if it is a chemical that:*

- *Is solid or in a dispersion, and*
- *Consists of particles in an unbound state or as an aggregate or agglomerate, at least 50% (by number size distribution) of which have at least one external dimension in the nanoscale"*[2]

Agglomeration refers to more loosely bound particles and aggregation signifies very tightly bound or fused particles.

This topic will focus on engineered nanomaterials (ENMs) and excludes nanoparticles from natural sources (e.g., fires, viruses, sea spray) and from human activity origin (e.g., diesel particulate matter, welding fume, sand blasting). The latter are discussed in their respective chapters within the review.

ENMs arise from the application of nanotechnology. Nanotechnology is defined as:

> *"The application of scientific knowledge to manipulate and control matter in the nanoscale to make use of size- and structure-dependent properties and phenomena distinct from those associated with individual atoms or molecules or with bulk materials."*[1]

Nanomaterials can exhibit unique or enhanced physicochemical properties and different toxicological behaviours to the equivalent chemical at the macro-scale. Physicochemical properties that can change at the nanoscale include:

- Colour
- Chemical reactivity
- Electrical conductivity
- Magnetism
- Mechanical strength

14.3 What are the consequences of exposure?

Because nanotechnology is an emerging field, the potential for health implications from exposure to ENMs is also a developing area of scientific research. Safe Work Australia has commissioned two literature reviews on the topic, the most recent being published in January 2015[3]. This document titled *"Engineered Nanomaterials: An update on the Toxicology and Work Health Hazards"* provides a comprehensive review of the literature on the topic.

Key findings from the Safe Work Australia review included[3]:

- Bio-persistence of ENM in the lung is a critical property for induction of health effects from exposure to nanoparticles and nanofibers (e.g., Carbon nano tubes (CNTs) have potential fibrogenic activity in the lung).
- ENM particles tend to agglomerate, which complicates the extrapolation of findings from *in vitro* and *in vivo* studies to human exposures. Agglomeration has a significant impact on potential toxicological effects of exposure.

- The main findings of interest from *in vitro* and *in vivo* studies are the ability for ENMs to produce oxidative stress and increase inflammatory markers, in a wide range of cell types.
- Evidence suggests that inhaled ENMs are not readily adsorbed through the lungs into systemic circulation. After inhalation most nano particles are found to be exhaled or swallowed (due to being entrained in the mucus) and only a small fraction reaches the alveolar. But this small fraction is a concern due to uncertainty over the long-term health effects on the lungs.
- Evidence suggests that ENMs do not penetrate through intact or mildly abraded skin to the live cell layers below.
- There is a need for continued research on the potential health impacts from exposure to ENM in the workplace.
- ENMs cannot be considered collectively as either benign or harmful, each exposure scenario must be taken on a case-by-case basis.
- Risk assessment of health impacts from ENM exposures is hampered by limited toxicological and physical hazard information.

14.4 Who is exposed? And how are they exposed?

The use of nanomaterials in the resource sector is a developing technology. While most applications are in the testing and development phase, the future use of nanomaterials in the resource sector is inevitable. Some areas of current and potential use include:

- Sunscreens containing nano-TiO_2 and nano-ZnO particles [4]
- Treatment of mining effluent with nano-TiO_2 or nano-Fe_2O_3[5]
- Low rank coal flotation collection using polystyrene nanoparticles as collectors[6]
- Mineral processing applications [7, 8]
- Lubricant additives for equipment and machinery [9]
- Nanomaterial enhanced borehole drilling fluids [10, 11]
- Metal coatings made of nanoscale silica, zinc, and zinc-nickel used for corrosion protection [12]
- The use of 'nanofluid' in the oil and gas industry for drilling, completion, and for enhanced oil and gas recovery[12]

Resource sector workers are not involved in the direct manufacture of ENMs but are potential end-users. Possible avenues for worker exposures include dermal contact with these products (as liquids, settled dusts, or powders) and airborne exposure to nanoparticles or nanofibers emitted from composites and solid articles during cleaning and maintenance activities [13].

14.5 Current regulatory requirements

The main regulatory body for ENMs in Australia is the Australian Industrial Chemicals Introduction Scheme (AICIS) (formally NICNAS), which is responsible for the regulation of industrial ENMs used in chemical products such as paints, dyes, lubricants, plastics, surface coatings, etc. The Therapeutic Goods Administration (TGA) manages ENMs in therapeutic goods and medical devices, including nanoparticles within sunscreen. Exposure to ENMs within the workplace is controlled by the relevant health and safety regulator within each jurisdiction.

14.5.1 Coal mining, and metalliferous mines and quarries

There is no specific mention of ENM in the Coal Mining Safety and Health legislation, nor in the Mining and Quarrying legislation. However, ENM would be covered by requirements to manage exposures to hazardous chemicals, where they meet the requirements to be classified as a hazardous chemical. Products containing nanomaterials are mentioned within *RS 17 Recognised Standard for Hazardous Chemicals* and *QGL03 Guideline for Hazardous Chemicals*. Section 3.10 of both documents requires products containing ENMs to be labelled in accordance with the standard/guideline or to have a warning on the label based on the unknown risks of the product.

14.5.2 Petroleum and gas

The QLD Petroleum and Gas Production and Safety Act 2004, Chapter 9 Safety, does not specifically deal with the management of ENM related to operating plant. However, in some instances the QLD *Work Health and Safety Regulation 2011*, Chapter 7 Hazardous Chemicals may apply.

14.5.3 Explosives

There is no specific mention of ENM in either the *QLD Explosives Act 1999* or *QLD Explosives Regulation 2017*. Management of the risks associated with this hazard related to the use of explosives would be governed under the relevant health and safety related legislation for the site.

14.5.4 Exposure standards

Apart from carbon nanotubes (CNTs), carbon nano-fibres, nano-TiO_2, and recently nano-silver, there are no specific workplace exposure standards (WESs) for ENMs. Where there is no specific WES, it is generally accepted that the existing WES for the macro size chemical may not provide adequate health protection from the nanomaterial [3].

The existing health-based WESs (CNT, CNF, nano-TiO_2, and nano-silver) have been developed based on sub-chronic (i.e., 90-day) repeat exposure inhalation toxicity data. The majority of ENMs do not have toxicological data on them that will allow a specific health-based WES to be set [3]. Instead, authorities in Australia, Germany, the Netherlands, and the UK are implementing control banding approaches [3].

The US federal agency, National Institute for Occupational Safety and Health, (NIOSH) recommends that exposures to TiO_2 be kept below 2.4 mg/m^3 for fine sized TiO_2 and below 0.3 mg/m^3 for ultrafine (including engineered nanoscale) TiO_2, as time weighted averages for up to 10 hrs per day during a 40-hr work week [14].

As a comparison, the Australian WES for macro-sized TiO_2 is currently 10mg/m^3 (inhalable dust).

NIOSH recommends that exposures to CNTs and CNFs be kept below 1 $\mu g/m^3$ (0.001 mg/m^3) elemental carbon as a respirable mass 8-hour TWA [15].

NIOSH recommends that exposures to nano-scale silver (≤100 nm primary particle size) be kept below 0.9 µg/m^3 (0.0009 mg/m^3) (as an airborne respirable 8-hour TWA concentration [16].

14.6 Measurement and evaluation of the hazard

14.6.1 Control banding evaluation tools

Tailored control banding (CB) techniques are commonly used in the evaluation of risks from ENMs. CB tools are recommended for the selection of appropriate control measures for ENMs when there are no specific workplace exposure standards. Examples include: Nanosafer; Stoffenmanager-Nano; Nanotool; Precautionary Matrix; ECguidance; IVAM Guidance; ISO; and ANSES [17]. A recent study examined the differences between these tools in real workplace exposure scenarios and found the Stoffenmanager-Nano Tool, Nanotool, and Nanosafer tool all offered good correlation with workplace measurement data [17]. The authors recommended the Nanotool and the Stoffenmanager-Nano tool as they had more comprehensive advantages based on both quantitative and qualitative assessment data [17]. Another recent study examined eight CB tools and found that the same, or more stringent control measures, were recommended by the tools, compared with proposed WESs [18]. They suggested that CB tools would generally provide prudent exposure control guidance [18].

14.6.2 Workplace measurements

The measurement of workplace exposures to ENMs is challenging due to several factors including the diversity of ENMs, tendency for particles to agglomerate or aggregate, background concentrations of nanoparticles, and different measurement parameters. The different measurement parameters include:

- Mass concentration
- Number concentration
- Size distribution
- Shape
- Chemistry
- Surface area

NIOSH has developed a 'Nanomaterial Exposure Assessment Technique (NEAT Method 2.0)[19]. This technique involves a combination of sampling approaches including filter-based gravimetric sampling, chemical analysis, microscopic analysis, and direct reading/hand-held counters (CPS and OPC) [19]. The authors of the NIOSH NEAT 2.0 method report that there are no recommended sampling and analytical methods developed specifically for engineered nanomaterials, except for TiO_2, carbon nanotubes (CNTs), and carbon nano-fibres (CNFs). The existing analytical methods published in the NIOSH Manual of Analytical Methods (NMAM) or from US federal agency, Occupational Safety and Health Administration (OSHA) must be modified slightly, while still retaining their integrity, for ENM sampling [19]. These modifications include maximizing the flow rate, within the prescribed range of the method, to improve the likelihood of collecting sufficient mass for elemental analysis.

Sampling for CNTs or CNFs is performed following NIOSH Method # 5040, using a 25 mm quartz fibre filter and a respirable cyclone, with analysis for elemental carbon (EC) [19]. The collection of a second sample on an open-face filter for analysis by electron microscopy assists in characterizing the CNT/CNF materials [19].

The NIOSH NEAT 2.0 approach uses a similar basic occupational hygiene approach to that described by Safe Work Australia [20] and the Organisation for Economic Co-operation and Development (OECD) [21]. The recommended approach involves a three-tier assessment process. The three tiers are:

1. Tier one: involves a standard occupational hygiene survey of the process area, plus measurement, to identify likely points of particle emission.

2. Tier two: involves measuring particle number and mass concentration to evaluate emission sources, workers' breathing zone exposures and effectiveness of workplace controls. A combination of instruments such as a portable condensation particle counter, optical particle counter and photometer can be used effectively.

3. Tier three: involves repeating Tier Two measurements together with simultaneous collection of particles for off-line analysis of particle size, shape and structure and chemical composition. Off-line particle analysis can be compared to real-time measurement results [20].

14.7 Summary of health monitoring data currently available to RSHQ

14.7.1 Status of the data available to RSHQ

The use of ENMs in the resource sector is an emerging potential hazard. No quantitative or qualitative data could be made available by RSHQ on the use or exposure to ENMs.

14.7.2 How could data collection and management be improved?

RSHQ should consider monitoring:

- The growth in use of ENMs in the resource sector

- The emerging scientific literature on potential adverse health effects from ENM exposures

RSHQ should work together with the federal regulatory bodies, including the Australian Industrial Chemicals Introduction Scheme (AICIS) and the Therapeutic Goods Administration (TGA), to ensure that appropriate regulatory steps are taken to ensure any unacceptable risk of harm to workers in the resource sector from ENMs is identified and managed.

Where ENMs are in use, the hierarchy of control measures should be applied to ensure workers' health is protected. Given the gaps in scientific knowledge, the risks from exposure should not be underestimated. Control banding techniques can be applied to assist with the risk management process.

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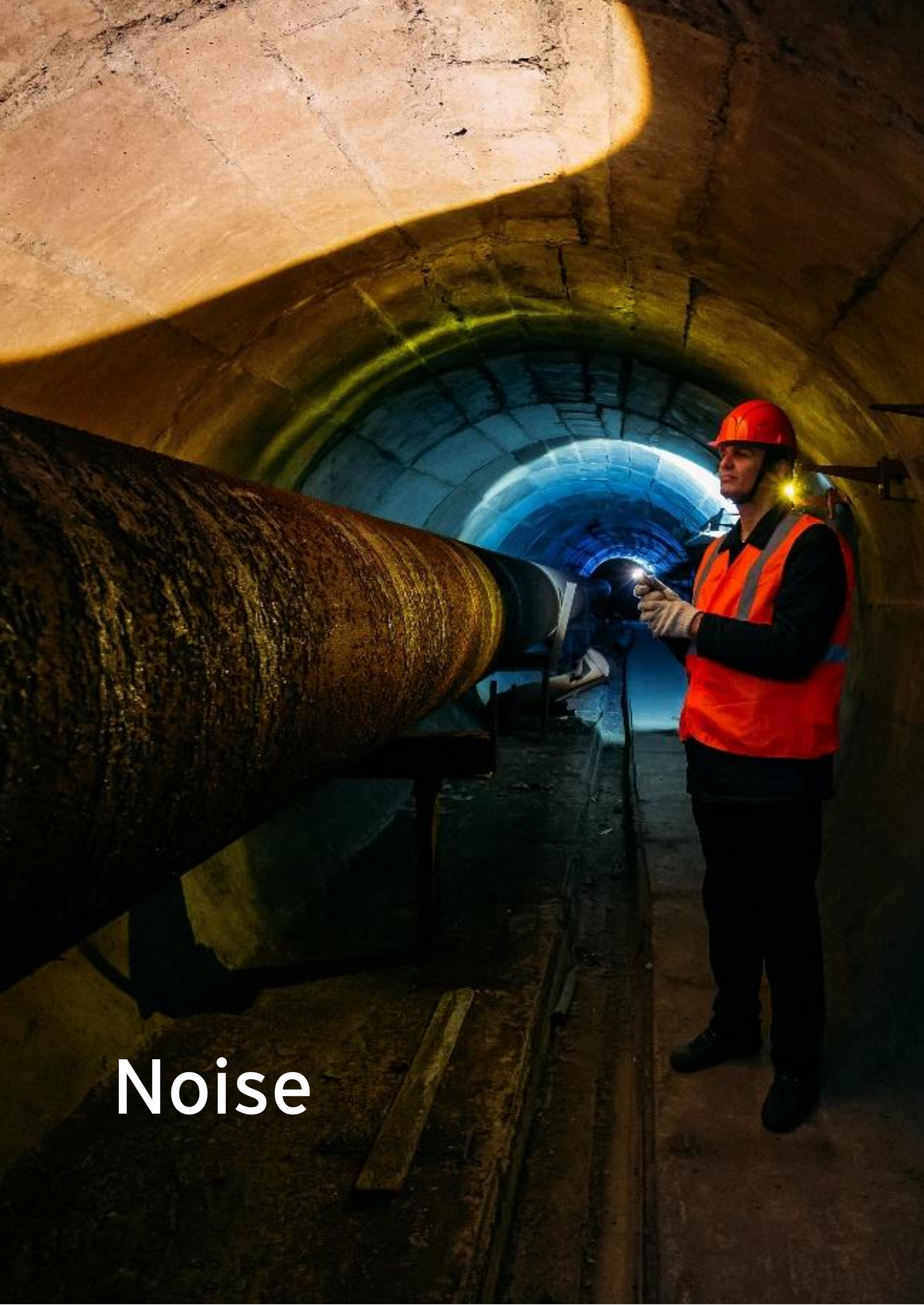


Noise

15. Noise

15.1 Overview

Summary of the health effects presented by the risk
The most common and serious health impact of noise exposure is Noise Induced Hearing Loss (NIHL). NIHL is caused by long term exposure to continuous, intermittent, and fluctuating noises [1]. But hearing loss can also occur from a single or repeated exposure to sudden high impact or explosive noise, known as acoustic trauma [1]. Noise exposure can cause two types of damage, depending on the noise energy level, either temporary threshold shift (TTS) or permanent threshold shift (PTS) [1]. Noise is a stressor that can cause health effects outside the auditory system. Although it can be difficult to study due to confounding factors (e.g., smoking, age, socioeconomic status, diet, alcohol intake, etc.), there is some limited evidence of negative health effects on several non-auditory bodily systems, including: ► Cardiovascular health effects [2], ► Depression [3], ► Type 2 diabetes [4], ► Sleep disturbance effects, and ► Low birth weight/ pre-term births as well as effects on children's hearing from the mother's exposure to noise during pregnancy [5]
What we know about the risk (available data and evidence from RSHQ and other sources)
Noise is ubiquitous in the resource sector with most operational and maintenance workers within coal mines, metalliferous mines, quarries, and petroleum and gas drilling and processing sites being routinely exposed to noise and in many cases exposed to levels exceeding the exposure standard. The most recent survey completed by Safe Work Australia (the Australian National Hazard Exposure Worker Surveillance (NHEWS)) in 2008 found that 68% of survey respondents who worked in mining reported exposure to loud noise at work [6]. The report also found that on a typical day, those who worked in mining were exposed to loud noise for an average of 7.3 hours [6]. The noise exposure data held by RSHQ is minimal and consists of workers' compensation claims data and some mainly qualitative HRA information. However, the available data indicates that noise is a pervasive and ongoing issue across all the industry sectors—mining, quarrying, explosives, and petroleum and gas. The accepted workers' compensation claims data (2016/17 to 2020/21) includes 688 claims for industrial deafness. Over half (57%) of the claims originated from workers within open cut coal mining. The other two largest groups were underground copper ore mining (14%) and underground coal mining (13%). Claim numbers appear to be stable over the five-year period, which indicates the high noise exposures in industry are remaining unchanged.

The petroleum and gas safety information bulletin no. 10 (2020), provides a summary of the rig health risk assessment project that found, of the health hazards surveyed, only noise was determined to be greater than a low risk of exposure. The HRA process found that derrickman, motorhand, mud-pump operator and the maintenance crew have a high risk of exposure to noise. The major sources of noise include the mobile compressor packs, mud pumps, rig power packs, and mobile cement pumping equipment.

How we can learn more about the impact of this risk in the resources sector in Queensland

Noise is a health hazard that is poorly managed and control measures rely too heavily on often minimally effective personal hearing protective devices. Unless further action is taken, the industry will continue to see the current rates of claims for industrial deafness (688 claims over the past 5 years). Importantly, occupational NIHL is entirely preventable and should not be viewed as just part of the job. Levels of NIHL in the resources sector have not seen significant improvement over many decades. To obtain a major change in NIHL a concerted effort is required by all stakeholders, government, manufacturers, suppliers, employers, and workers. A cooperative effort will only bring far-reaching change if it can be employed on an industry wide basis. The focus needs to be on reducing noise exposures via higher order controls that create work environments which do not continually expose workers to noise levels in excess of the National Exposure Standard.

15.2 What is the health hazard?

Noise is defined by Safe Work Australia as *"any unwanted or damaging sound" and sound as "energy in the form of pressure waves that move through air and other media and are capable of exciting in a listener the sensation of hearing"* [7]. Noise is considered a hazard if exposure may result in harm to the hearing of a person. Harm may result from repeated/ chronic exposure to noise or acute single exposures to high impact or explosive sound. Risk of harm is related to the total amount of noise a worker is exposed to and is expressed as an energy level. The energy level is defined as a function of the sound pressure of noise (measured in decibels) and the duration of exposure over time [8].

15.3 What are the consequences of exposure?

15.3.1 Auditory health effects

The most common and serious health impact of noise exposure is Noise Induced Hearing Loss (NIHL). NIHL is caused by long term exposure to continuous, intermittent, and fluctuating noises [1]. But hearing loss can also occur from a single or repeated exposure to sudden high impact or explosive noise, known as acoustic trauma [1]. Noise exposure can cause two types of damage, depending on the noise energy level, either temporary threshold shift (TTS) or permanent threshold shift (PTS) [1].

With TTS, hearing recovers within 24-48 hours [9]. However, animal research has shown that TTS at a young age results in accelerated age-related hearing loss [10]. It has also been shown to cause what is known as "hidden hearing loss", damage that does not result in pure-tone threshold shift [1]. This hidden hearing loss involves a mechanism called cochlear synaptopathy (synaptic damage), a loss of connections between the inner hair cells and their associated neurons [1]. The potential reversibility of synaptic damage is still being investigated [5]. The mechanisms involved in TTS and PTS are different and although TTS is an indicator of over exposure to noise, it is not a reliable predictor of PTS [5]. However, as the recent research on synaptic damage from TTS indicates, there may be permanent damage caused by TTS even though full recovery of the threshold shift occurs after a TTS [5].

NIHL with associated PTS is the result of damage to cochlear hair cells [1]. Once damaged, these hair cells cannot regenerate and is therefore permanent. Damage to cochlear hair cells results from several mechanisms – mechanical, ischemic, and metabolic [1]. Although, mechanical damage was originally thought to be the primary mechanism, research indicates that mechanical damage occurs from impulse noise exposures of at least 130 dB sound pressure level (SPL) or continuous noise exposures of 120 dB [11]. In fact, most occupational NIHL is caused by ischemic (i.e. noise exposure causes a restriction of blood flow in cochlear blood vessels) and, more commonly, metabolic processes [5]. The metabolic pathway involves oxidative stress [5]. Exposure to noise increases reactive oxygen species (ROS) or free radicals in the cochlea immediately after noise exposure and for up to 10 days following the exposure, but before signs of damage occur [5]. Increased ROS concentration is now well established as a damage initiating mechanism [5]. However, how noise exposure leads to increased ROS in the cochlea, is still not well understood [12].

NIHL is recognised as a "notch" in the worker's audiometric thresholds, involving a loss of hearing at the 3000-6000 Hz range, with better hearing in the frequencies either side of this range [5]. In contrast, age-related hearing loss starts at higher frequencies of around 8000 Hz. Combined NIHL and age-related loss increases the size of the "notch" [5]. Although NIHL is thought to normally appear equally in the two ears (bilaterally), a recent systematic review has shown that hearing loss occurs more on one side (asymmetrically) in 2-22% of workers and that the left ear is most often more affected even after adjusting for the worker's dominant hand [13]. Differences between the two ears' auditory processing mechanisms is currently being investigated as an explanation for this finding [13].

Research has shown that NIHL accumulates most quickly in the first 10-15 years of exposure and slows over time even as exposure continues. Whereas age-related hearing loss accelerates later in life [5].

Tinnitus, a characteristic sensation of ringing or buzzing in the ears without an external stimulus, is another auditory health effect associated with noise exposure. Tinnitus can result from causes other than noise but if a worker also has NIHL, it is assumed the tinnitus is caused by noise [5]. There is also a correlation between the severity of both conditions and it is often found in both ears but may appear in one ear only [5]. SafeWork Australia estimates that 20% of those who suffer from NIHL also suffer from tinnitus [14] .

15.3.2 Non-occupational exposures

Non-occupational exposure to noise can contribute to a workers' overall exposure and subsequent development of NIHL. For workers exposed to high occupational noise levels, some research indicates that exposures outside of work contribute little to the overall risk, with the exception of firearms use [15]. Whereas other research suggests non-occupational exposures can significantly contribute to overall risk of NIHL [16].

A growing area of concern is exposure by youth to unsafe noise levels from personal listening devices (i.e. use of earphones and EarPods with smart phones, etc.). Research indicates that sound pressure levels from personal listening devices can produce sound levels of up to 121 dB(A) at the highest volume and peak levels as high as 139 dB [17] and that 17 to 23 year-olds spend an average of 2 hours per day, 6.5 days per week listening to personal music players [18]. If young workers entering the mining industry already have hearing damage, it will be even more important to ensure their hearing is protected in the work environment.

15.3.3 Other non-auditory health effects

Noise is a stressor that can cause health effects outside the auditory system. Although it can be difficult to study due to confounding factors (e.g., smoking, age, socioeconomic status, diet, alcohol intake, etc.), there is some evidence of negative health effects on several non-auditory bodily systems. Some research has suggested a moderate association between noise exposure and cardiovascular health effects [2]. The mechanism is thought to be related to the bodies stress response from noise leading to elevated heart rate and blood pressure and that over time this chronic stress leads to hypertension [2]. However, a recent meta-analysis produced for the World Health Organisation and International Labour Organisation, has found that there is inadequate to limited evidence of the relationship between noise exposure and cardiovascular disease [19].

There is some limited evidence of an association between high noise exposures and depression [3], Type 2 diabetes [4], sleep disturbance effects, and low birth weight/ pre-term births as well as effects on children's hearing from the mother's exposure to noise during pregnancy [5].

15.3.4 Ototoxins

Exposure to some chemicals (e.g. solvents, fuels, metals, fertilisers, herbicides, and pharmaceuticals) has been associated with hearing loss and tinnitus. A recent study using data from a large US CDC National Health and Nutrition Examination Survey found evidence of an association between exposure to benzene, ethylbenzene, and toluene and high frequency hearing loss [20]. However, the study did not find that noise exposure potentiated the effect [20], which contrasts with other studies that have reported that joint exposures to solvents and noise affects hearing loss [21, 22]. Further research is required to understand the audiometric health effects from combined ototoxic exposures and noise.

Smoking has also been found to have a synergistic effect with noise exposure increasing the risk of NIHL due to exposure to the ototoxin, carbon monoxide, within the smoke [5].

15.4 Who is exposed? And how are they exposed?

This section covers worker exposure in MMQ, and Petroleum and Gas. While no health surveillance data could be made available by RSHQ for the preparation of this report, there is discussion about an Australian study in section 1.8.3 below.

15.4.1 Coal mining and metalliferous mines and quarries

Within coal mines, metalliferous mines, and quarries, most operational and maintenance workers are routinely exposed to noise and in many cases are likely to be exposed to levels exceeding the exposure standard.

Exposure occurs as part of routine operations and maintenance activities involving the use of machinery, tools, and equipment, including extractive equipment, hand-held tools, transport, and ancillary equipment. Table 27 below provides a summary of some of the common sources of noise in open cut and underground mining and within processing plants.

Table 27: Sources of Noise in Mining

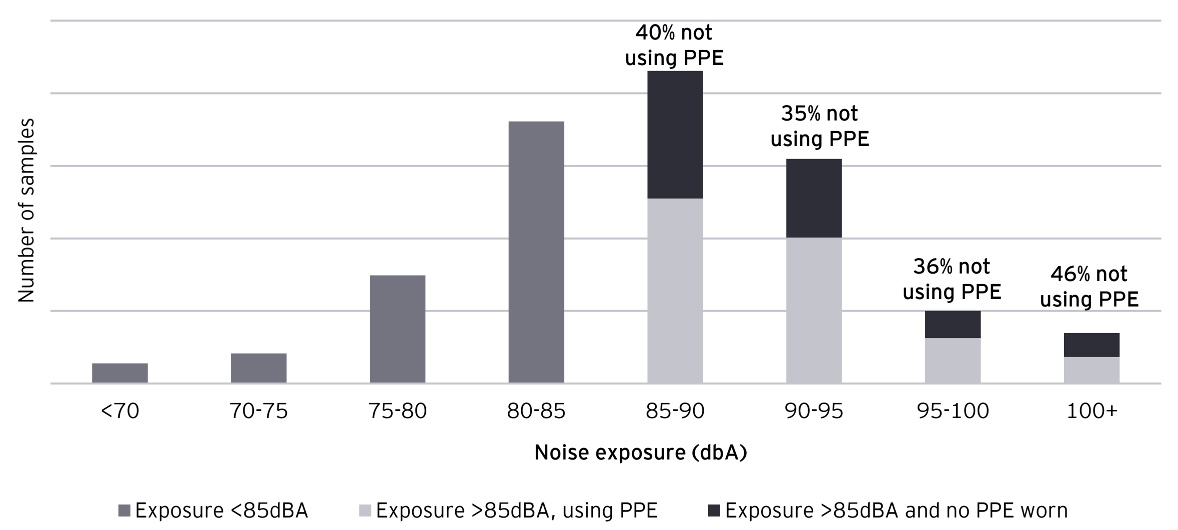
Open Cut Mining	Sound Level db(A)	Underground Mining	Sound Level db(A)	Processing Plants	Sound Level db(A)
Rotary drills	95-106	Air guns	115	De-waterers	90-100
Percussion drills	103-120	Jumbo drills	103-106	Jaw crushers	90-100
Crawler tractors	96-107	Continuous miner	94-98	Vacuum pumps	90-100

Open Cut Mining	Sound Level db(A)	Underground Mining	Sound Level db(A)	Processing Plants	Sound Level db(A)
Electric shovels	75-90	Longwall shearers	90-94	Autogeneous grinders	90-100
Diesel shovels	85-102	Chain conveyors	100-105	Classifying screens	90-102
Haul trucks	84-109	Roof bolters	110-112	Car shake-outs	103-116
Scrapers	85-111	Shuttle car	93	Fans and blowers	96-100
Front end loaders	104-108	Hydrocar	90	Chutes and hoppers	100-108
Graders	85-100	Boggers	95-100		
Coal augers	89-100	Ventilation fans	90-100		
Dragline	92-101				

Sources: [23, 24]

The Department of Mines, Industry Regulation and Safety in Western Australia published a *Mines Safety Bulletin No.152* in 2018, which provided an analysis of noise exposure data submitted to their Safety Regulation System (SRS) from 17 May 2017 to 23 April 2018 [25]. The data shows that a large percentage of mine workers are regularly exposed to noise levels that could cause NIHL. A trend towards overreliance on personal hearing protection instead of engineering controls was also noted. Figure 25 below summarises their results.

Figure 25: Distribution of daily noise exposure measurement submitted through WA SRS 17 May 2017 – 23 April 2018. (Source: [25]).



NIOSH reports that 80% of miners go to work in an environment where they are exposed to noise levels exceeding LAeq,8h 85 dB(A). Additionally, NIOSH's analysis of audiograms found that 90% of coal miners and 49% of metal/non-metal miners have a hearing impairment at age 50, compared with only 10% of other non-miners [26]. Noise is not only a problem in the mining industry it is also a significant health and economic problem more generally. Safe Work Australia reports that between July 2002 and June 2007 there were about 16 500 workers' compensation claims for industrial deafness [7]. In 2006-07 the Australian mining industry had the highest claims rate for industrial deafness with 1.8 claims per 1000 workers [7].

15.4.2 Petroleum and gas

Within petroleum and gas, most operational and maintenance workers on drilling sites and gas processing facilities are routinely exposed to noise and in many cases are likely to be exposed to levels exceeding the exposure standard. Impact noise exposures may also present a risk.

The petroleum and gas safety information bulletin no. 10 (2020), provides a summary of the rig health risk assessment project that found, of the health hazards surveyed, only noise was determined to be greater than a low risk of exposure. The HRA process found that derrickman, motorhand, mud-pump operator and the maintenance crew have a high risk of exposure to noise. The major sources of noise include the mobile compressor packs, mud pumps, rig power packs, and mobile cement pumping equipment.

US [27] and Canadian [28] data has found that petroleum and gas workers' exposure to noise exceeds exposure standards and workers are at risk of NIHL. Table 28 summarises data from WorkSafe British Columbia on noise exposures in the petroleum and gas sector.

Table 28: WorkSafe British Columbia noise exposure data for petroleum and gas sector

Work Location/ Activity	Example Noise Level dB(A)
Dog house	80 - 84
Mud tanks	86 - 90
Rig floor	86 - 100
Mix shack	90 - 93
Mud pumps	90 - 95
Pump house	95 - 100
Compressors	99 - 105
Generator building	103 - 111
Fracturing	104 - 107
Vac truck	102 - 110
Rig engine room	105 - 115
Pump trucks	112 - 116

Source: [28]

15.5 Current QLD regulatory requirements for noise management

15.5.1 Coal mining

The *QLD Coal Mining Safety and Health Regulation 2017*, section 91 covers the requirement for the mine's safety and health management system to provide ways of ensuring that each coal mine worker's exposure to noise is kept to an acceptable level; and the worker is not exposed to noise levels exceeding the exposure levels. The system must provide for the following:

- ► Supplying personal protective equipment for persons in the work environment if there is no practical way of reducing the persons' noise dose to comply with the exposure standard
- ► Monitoring and recording noise levels in the work environment
- ► Keeping the records in a location that is easily accessible by each coal mine worker at the mine

- Identifying, by an appropriate warning sign, each part of the mine where there are excessive noise levels

The *QLD Coal Mining Safety and Health Regulation 2017, Division 2,* covers the Coal Mine Workers' Health Scheme. Workers' hearing is examined as part of this scheme via audiometric testing.

Also, *QGN 22: Guidance Note for Management of Noise in Mines* (2014 version 1), provides a guide to the risk management of noise in mines and quarries, including the assessment of exposures and health surveillance. Section 2.6.2 of QGN22 covers the requirements for health surveillance. In accordance with this section, "audiometric testing should be considered for workers who are exposed to noise above the exposure limit set by Safe Work Australia or by the organisation's noise policy (whichever is the lower) and/or ototoxic agents (Appendix C, AS/NZS 1269.0)". Audiometric testing should be carried out in accordance with AS/NZS 1269.4.

15.5.2 Metalliferous mines and quarries

The *QLD Mining and Quarrying Safety and Health Regulation 2017* does not cover noise in its own specific section but mentions noise as a hazard that requires monitoring. The main requirements relating to noise are provided via the guidance note—*QGN 22: Guidance Note for Management of Noise in Mines (2014 version 1)* (See notes above in section 15.5.1).

15.5.3 Petroleum and gas

The *QLD Petroleum and Gas Production and Safety Act 2004*, Chapter 9 Safety, does not specifically deal with the management of noise exposures related to Operating Plant. Noise would be required to be managed as part of the normal requirements of a safety management system (SMS) and in some cases the *QLD Work Health and Safety Regulation 2011*, Chapter 4, Part 4.1 Noise, would apply.

15.5.4 Explosives

There is no specific mention of noise exposure management in either the *QLD Explosives Act 1999* or *QLD Explosives Regulation 2017*. Management of the risk associated with this hazard related to the use of explosives would be governed under the relevant health and safety related legislation for the site.

15.6 Current exposure standards

15.6.1 Coal mining

The QLD Coal Mining Safety and Health Regulation 2017, section 91 states the exposure standard for noise is "the dose limit stated in NOHSC's document called 'National Standard for Occupational Noise 2nd edition [NOHSC:1007 (2000)]"[29].

The National Exposure Standard is:

"The national standard for exposure to noise in the occupational environment is an eight-hour equivalent continuous A-weighted sound pressure level, **$L_{Aeq,8h}$, of 85dB(A).** For peak noise, C-weighted peak sound pressure level, **$L_{C,peak}$, of 140dB(C).** The exposure to noise is taken to be that measured at the employee's ear position without considering any protection, which may be afforded by personal hearing protectors."

$L_{Aeq,8h}$, of 85dB(A)	Eight-hour equivalent continuous A-weighted sound pressure level in dB(A) referenced to 20 micropascals, means that steady noise level which would, in the course of an eight-hour period, cause the same A-weighted sound energy as that due to the actual noise over an actual working day. LAeq,8h is to be determined in accordance with Part 1 of Australian/New Zealand Standard AS/NZS 12691.

$L_{C,peak}$, of 140dB(C)	Peak noise level means C-weighted peak sound pressure level in decibels measured by a sound level meter with a peak detector-indicator characteristic complying with Australian Standard AS 1259.12.

Source: [29]

15.6.2 Metalliferous mines and quarries

The *QLD Mining and Quarrying Safety and Health Regulation 2017*, schedule 5 states the exposure standard for noise is "the dose limit stated in NOHSC's document called *'National Standard for Occupational Noise 2nd edition [NOHSC:1007 (2000)]'*" (see above definition of the national exposure standard).

15.6.3 Petroleum and gas

The *QLD Petroleum and Gas Production and Safety Act 2004*, Chapter 9 Safety, does not specifically deal with the management of noise exposures related to Operating Plant. In some cases, the *QLD Work Health and Safety Regulation 2011*, Chapter 4, Part 4.1 Noise, would apply. This Part defines the exposure standard for noise as an $L_{Aeq,8h}$ of 85 dB(A) or $L_{C,peak}$ of 140 dB(C). Although the exposure standard levels are the same, the WHS legislation does not reference the 2000 NOHSC National Exposure Standard document.

15.7 Exposure standard trends in other jurisdictions (mining and non-mining)

The same exposure standards ($L_{Aeq,8h}$ 85 dB(A) and L_{Cpeak} 140(C)) for noise apply in all Australian jurisdictions in mining and non-mining industries. Requirements for audiometric testing are also substantially the same across the jurisdictions.

15.8 Measurement and evaluation of the hazard

15.8.1 Current methods

The current methods for the assessment of workers' exposure to noise include the use of sound level meters and dosimeters (personal sound level meters) in accordance with AS/NZS 1269.1:2005 *Occupational noise management—measurement and assessment of noise emission and exposure*. As well as health surveillance of workers via audiometric testing in accordance with AS/NZS 1269.4:2014 *Occupational noise management auditory assessment*. This standard is a comprehensive document covering the key requirements for the performance of audiometric testing.

15.8.2 Emerging technology for noise exposure assessment

Research has indicated that iOS smartphones with certain applications and a calibrated external microphone may be used to accurately measure workers' personal exposures to noise [30]. It should be noted that this is an emerging technology and would not replace the current equipment requirements specified in the AS/NZS 1269 series on noise exposure assessment and management.

Wearable sensors/ wearable technology is a rapidly developing field of research. A recent study examined workers' opinions on the type of hazards they would like to be able to receive regular real time feedback on at work. Noise was one of the main hazards that workers surveyed wanted information on from wearable technology, including whether their hearing protection sufficiently protects them and receiving warnings if they were being exposed to excessive noise [31].

15.8.3 Review of current published data on NIHL in the resource sectors

A recent US study analysed audiograms from 1.9 million workers including 9389 workers in the mining industry and 1076 in the oil and gas extraction sectors [27]. They reported that the presence of NIHL in the mining industry was 24% and, in the oil and gas sector, 14% compared with 16% for all industries combined [27]. The study also reported that nearly all subsectors within the mining and oil and gas sectors have significantly higher adjusted risk of NIHL than the reference industry (Couriers and Messengers).

An Australian study that analysed hearing threshold levels (HTL) of workers commencing employment in New South Wales coal mines found that nearly one fifth of the male workers (14.8 – 20.1%) presented with an audiometric notch at 4kHZ indicating a potential NIHL present before commencing employment and therefore a requirement to try to conserve these workers hearing and prevent further loss [32].

15.9 Summary of health monitoring data currently available to RSHQ

15.9.1 Data provided

- Accepted Worker's Compensation claims for industrial deafness
- Health Risk Assessments performed for individual sites

15.9.2 Workers' compensation data

The accepted workers' compensation claims data for the period 2016/2017 to the incomplete year of 2020/2021 includes 688 claims for industrial deafness. Table 29 provides a breakdown of the claims based on industry group and year of claim acceptance. Over half (57%) of the claims originated from workers within open cut coal mining. The other two largest groups were underground copper ore mining (14%) and underground coal mining (13%). Oil and gas extraction and explosives manufacturing had low claim numbers (3 and 6 claims, respectively). Claim numbers appear to be stable over the five-year period, which indicates the high noise exposures in industry are remaining unchanged.

Table 29: Summary of accepted workers compensation claims data for the period 2016/2017 – 2020/2021

Industry Group	2016/17	2017/18	2018/19	2019/20	2020/21*	Total
Bauxite Mining Open Cut	1	2	1	3	3	10
Bauxite Mining Underground				1		1
Coal Mining Open Cut	76	89	95	89	45	394
Coal Mining Underground	28	22	19	15	8	92
Copper Ore Mining Open Cut		1	1			2
Copper Ore Mining Underground	21	6	19	30	22	98
Drilling and Boring Support Services	1		1			2
Explosives Manufacturing		1	2	3		6
Gold Ore Mining Open Cut			1			1
Gold Ore Mining Underground	2			1		3
Gravel and Sand Quarrying	1		1	1		3
Metal Ore Mining n.e.c. Open Cut			1		2	3
Mineral Exploration (Own Account)			1	1		2

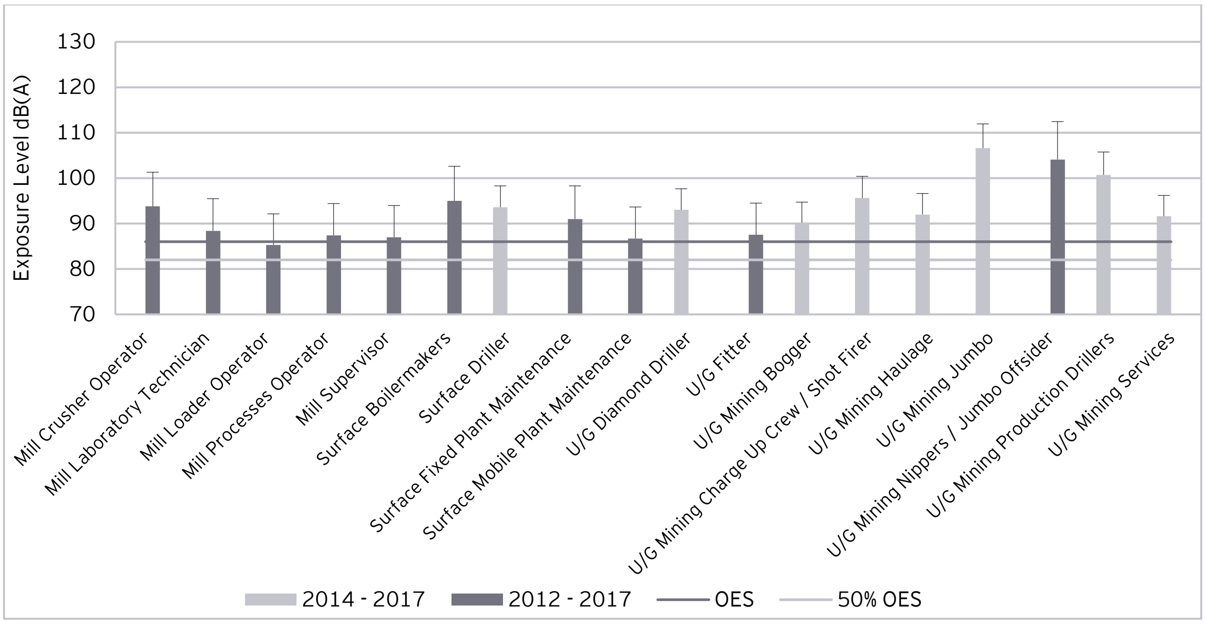
Industry Group	2016/17	2017/18	2018/19	2019/20	2020/21*	Total
Mineral Exploration Services	1	2	1	2		6
Mineral Sand Mining	1	1		1		3
Oil and Gas Extraction		1	1	1		3
Other Construction Material Mining	3	2	2	5	2	14
Other Mining Open Cut	2	2		2	3	9
Other Mining Support Services	3	3	5	2	1	14
Other Mining Underground	1	4		1	1	7
Other Petroleum and Coal Product Manufacturing	1					1
Petroleum Exploration (Own Account)		1	2			3
Petroleum Refining and Petroleum Fuel Manufacturing		4		2	1	7
Silver-Lead-Zinc Ore Mining Open Cut	1	1				2
Silver-Lead-Zinc Ore Mining Underground			1		1	2
Grand Total	**143**	**142**	**154**	**160**	**89**	**688**

*Incomplete data for the 2020/2021 financial year due to the date data was provided (data up to 31st December 2020)

15.9.3 Health Risk Assessments (HRAs)

The Health Risk Assessments provided included reviews completed for specific sites, including coal mines (3 reports), metalliferous mines (1 report), and petroleum and gas drill rig sites (6 reports). Noise was consistently listed as one of the top occupational health hazards in all HRA reports. Most of the reports did not include specific quantitative data on noise exposures. However, one HRA prepared for a metalliferous mine included statistical analysis of the site's available noise exposure data and the results are presented in Figure 26. The data indicates that all similar exposure groups (SEGs) examined had mean (AM/MVUE) exposures in exceedance of the National Exposure Standard.

Figure 26: Example of noise exposures in an underground metalliferous mine



15.10 Status of the data available to RSHQ

The noise exposure data held by RSHQ consists of workers' compensation claims data and some mainly qualitative HRA information. However, the available data indicates that noise is a pervasive and ongoing issue across all the industry sectors—mining, quarrying, and petroleum and gas. In general, across the industry, noise is a health hazard that is often poorly managed and control measures rely too heavily on hearing protective devices. Unless further action is taken, the industry will continue to see the current rates of claims for industrial deafness.

15.11 How could data collection and noise exposure management be improved?

Central to the discussion is the premise that occupational NIHL is entirely preventable and should not be viewed as just part of the job. Levels of NIHL in the resources sector has not seen significant improvement over many decades. To obtain a major change in NIHL a concerted effort is required by all stakeholders, government, manufacturers, suppliers, employers, and workers. A cooperative effort will only bring far-reaching change if it can be employed on an industry wide basis. Importantly, no one control measure will result in the major improvement needed, a combination of controls is required, including new designs, new technology, buy quiet programs, retrofitted engineering measures, and improved hearing conservation programs. The focus needs to be on reducing noise exposures via higher order controls that create work environments which do not continually expose workers to noise levels in excess of the National Exposure Standard. The South African mining industry has had a focus on the use of engineering controls as part of a hearing conservation program and has demonstrated, through published case studies, that mine machinery noise intensity levels can be reduced by up to 10 dBA, a significant reduction in noise emission [33].

15.12 References

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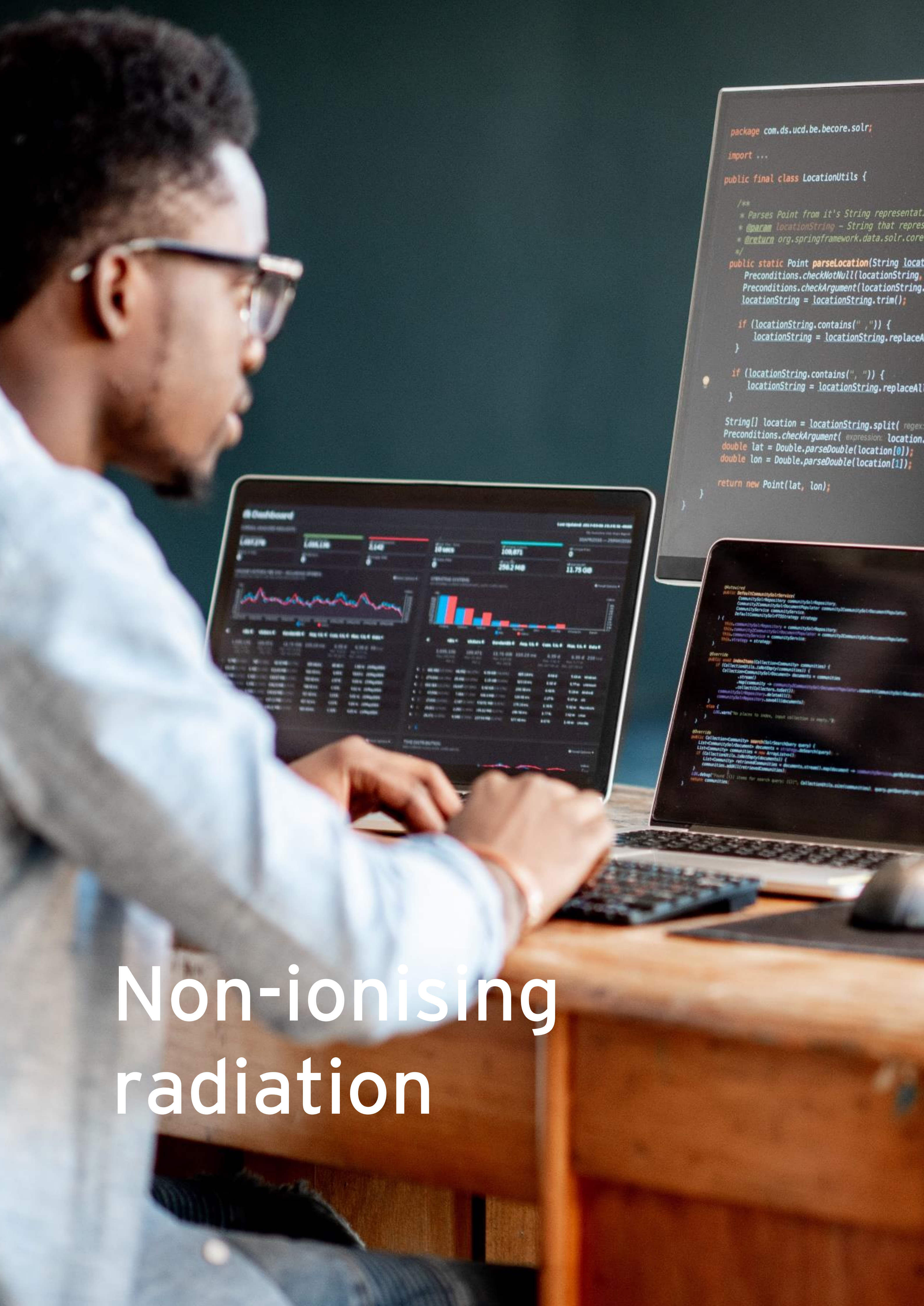


Non-ionising radiation

16. Non-ionising radiation

16.1 Overview

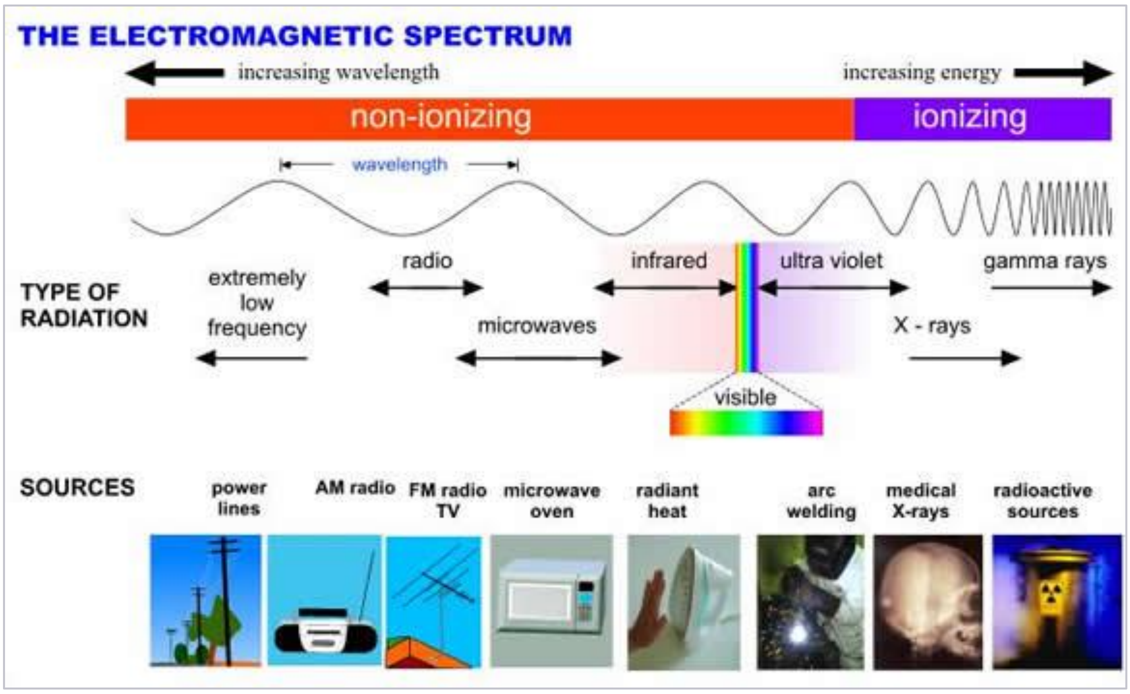
Summary of the health effects presented by the risk
The health effects from exposure to non-ionising radiation depends on the frequency and wavelength of the radiation, the distance the person is from the source and the frequency and duration of exposure. At the lower part of the electromagnetic spectrum (i.e., extremely low frequency electromagnetic energy (ELF EME) and radio frequency (RF) energy) there is little to no potential for health effects of exposed workers in the resource sector. But as the frequency increases, health effects become more apparent. Exposure to infrared (IR) and ultraviolet (UV) radiation from the sun and from artificial sources, can result in damage to the eyes and the skin. Exposure to UV radiation is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) because of its causal involvement in melanoma and non-melanoma skin cancers, including squamous cell carcinoma [1]. UV radiation can also cause damage to the lens of the eye resulting in keratitis and cataracts. Outdoor workers in the Queensland mining and resource sector are at particularly high risk.
What we know about the risk (available data and evidence from RSHQ and other sources)
The non-ionising radiation exposure data provided by RSHQ is minimal and consists of scant qualitative data and no quantitative data. The data consists of some LTI reports and accepted workers' compensation disease claims combined with minimal qualitative information. The data was of little value in evaluating the magnitude and variability in exposures in the Queensland resources sector to non-ionising radiation and the hazard is presently likely to be underestimated. Of particular concern is exposure to solar UV radiation (UVR) for outdoor workers. Solar UV radiation exposure occurs year-round in most sectors within mining, petroleum and gas, and explosives. Those with roles requiring outdoor work on a regular basis are most exposed. Outdoor workers in Queensland are particularly at risk and it has been estimated they receive on average approximately twice as much UV radiation over a two-day period as school children or at home workers [2]. In the summer months, unprotected outdoor workers are likely to exceed the occupational exposure limits for UVR within 10 minutes [3]. For outdoor workers, even when the UV Index is below 3, daily exposure limits are still likely to be exceeded. Regardless of whether work is completed out of direct sunlight, workers may still be exposed to high UVR levels from indirect and reflected UVR from the surrounding environment[3].
How we can learn more about the impact of this risk in the resources sector in Queensland
It is recommended that organisations within the Queensland resources sector be encouraged in include potential non-ionising radiation exposures in their health risk assessments, including quantitative assessments of workers' exposures to solar UV radiation.

16.2 What is the health hazard?

Radiation is a form of energy that travels as an electromagnetic wave or as high-speed particles. There are two forms of radiation—ionising and non-ionising. Non-ionising radiation does not have sufficient energy to 'ionise' (i.e., dislodge electrons from the nucleus of an atom as it passes through matter, forming ions) but does have enough energy to excite molecules and atoms causing them to vibrate faster. The hazard is exposure to electromagnetic waves.

This topic will focus on non-ionising radiation within the electromagnetic (EM) spectrum. Electromagnetic radiations (EMR) are categorised according to their frequency and wavelengths. There is an inverse relationship between frequency and wavelength, the higher the frequency (*f*) (measured in Hz), the shorter the wavelength (l) (measured in metres). As shown in the diagram below, the EMR spectrum goes from extremely low frequency (ELF), radio frequency (RF) and microwave (MW) frequency, to infrared (IR), visible and low energy ultraviolet light (UV). X-rays and gamma rays are also included in the EMR spectrum but are forms of ionising radiation and so are covered in a separate topic on ionising radiation. Sources of non-ionising radiation within the resources sector may include sunlight, welding, lasers, communication systems, and testing apparatus.

Figure 27: The Electromagnetic spectrum[4]



16.3 What are the consequences of exposure? Who is Exposed and how?

The below sections deal with consequences of exposure, who is exposed, and how they are exposed, according to each type of non-ionising radiation.

16.3.1 Extremely Low Frequency (ELF) Electro Magnetic Fields (EMF)

Extremely low frequency electric and magnetic fields are in the lower part of the electromagnetic spectrum (frequency range: 0 to 3000 Hz) [5]. Sources of exposure are generally artificial arising from the generation, distribution and use of electricity. In Australia, the alternating current (AC) electrical supply is at 50Hz [5] and therefore, the primary source of exposure to ELF will be at 50 Hz in the ELF band. Exposure to ELF electric and magnetic fields (EMF) is virtually unavoidable, both at work and outside of work due to the widespread use of electricity. ELF EMF exposures at work arise from working near powerlines, electrical wiring, and all electrical tools and appliances (e.g., computers, photocopiers, household appliances, tools, and equipment).

Whether exposure to extremely low frequency (ELF) electric and magnetic fields (EMF) causes any health effects, particularly for adults, is an area of ongoing scientific debate. In 2002, the IARC classified ELF magnetic fields as "possibly carcinogenic to humans", which denotes an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. The classification was based on pooled epidemiological data on childhood leukaemia [6].

In October 2005, the World Health Organisation (WHO) convened a Task Group of scientific experts to evaluate the risks to health that could exist from exposure to ELF EMF in the frequency range >0 to 100,000 Hz [6]. The Task Group reviewed evidence for several health effects and updated the evidence regarding cancer from the IARC evaluation conducted in 2002. Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF *electric fields* at levels generally encountered by members of the public. But did find evidence of some potential health effects from exposure to ELF *magnetic fields* [6]. The health effects (if any) depend upon the strength of the magnetic field at the source, the distance the person is from source and the duration of the exposure to the source [7].

In terms of short-term health effects, exposure to ELF magnetic fields induce electric fields and currents inside the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system [6]. With regards to long term health effects, most of the research has focussed on childhood leukaemia.

Several other health effects have been studied including other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioral effects and neurodegenerative disease [6]. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all these health effects was weak. In some instances (i.e., for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause the health effects studied [6].

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has reviewed existing data on health effects from ELF EMF and they concluded from the data:

> *The scientific evidence does not establish that exposure to the electric and magnetic fields found around the home, the office or near powerlines causes health effects. … There is no established evidence that the exposure to magnetic fields from powerlines, substations, transformers or other electrical sources, regardless of the proximity, causes any health effects. [8]*

16.3.2 Radio Frequency (RF) Radiation

Radio frequency electromagnetic energy (RF EME) is ubiquitous in the modern work and home environment. RF is the transfer of energy by radio waves (100 kHz to 300 HHz) [9]. The most common sources of RF EME include telecommunication networks, radio and TV broadcast infrastructure, wireless technology, mobile phones, tablets, and laptops. RF EME is also produced from industrial and medical devices and in radar and security scanning equipment [9].

In terms of potential for health effects from exposure RF EME, sufficiently high levels (well above occupational exposure limits) can heat biological tissue and potentially cause tissue damage [9]. However, RF EME levels routinely encountered in the home or at work (excluding RF workers) are too low to produce any significant heating or increases in body temperature [9]. There is no substantiated scientific evidence to support any adverse health effects from low-level exposure to RF EME associated with telecommunications and wireless technology at levels that are below the limits set by the ARPANSA RF Standard [9].

16.3.3 Infrared radiation

Infrared radiation (IR) is in the electromagnetic spectrum with wavelengths from 769 nm to 100,000 nm [10]. Apart from the sun being a natural source of infrared radiation, IR is usually an unintended by-product of processes that involve lighting or heating [7]. Any combustion processes, furnaces, glassmaking, and welding can produce IR [7]. IR is also used for thermal imaging applications. In the resources sector, IR exposure would occur from welding activities and thermal imaging techniques used as a diagnostic tool for monitoring the condition of equipment and machinery.

IR is divided into different bands as defined in standard ISO 20473:2007 *Optics and photonics -- Spectral bands [11]:*

- Near-Infrared (NIR, 0.78~3.0 μm)
- Mid-Infrared (MIR, 3.0~50.0 μm)
- Far-Infrared (FIR, 50.0~1000.0 μm)

IR typically cannot cause photochemical reactions with biological systems in the human body because of its low photon energy. However, absorption of IR photons does increase the kinetic energy of the tissue when the radiant energy is converted to heat. The increase in tissue temperature depends on the wavelength, exposure duration, and total energy absorbed. Most literature on the biological health effects of IR exposure focusses on effects on the eye [12]. Permanent damage to the eye can result from IR exposure [12]. Some recent research has also investigated the effects on the skin (i.e., reactive oxygen species generation, mitochondrial DNA, and nuclear DNA damage) from exposure to natural IR from the sun [13].

16.3.4 Lasers

Light Amplification by Stimulated Emission of Radiation (LASER) devices use low divergence means of intense monochromatic, coherent light in the IR, visible or UV wavelength. Lasers are classified according to their wavelength and therefore their safety by the AS/NZS IEC 60825.1: Safety of laser products, as follows [14]:

- Class 1—Safe under reasonably foreseeable conditions, including use of optical instruments for intrabeam viewing (eye is exposed to the direct or specularly reflected laser beam)

- Class 1M (Magnifier)—wavelength range 302.5—4000 nm, safe under foreseeable conditions, but may be hazardous if user employs optics within the beam
- Class 2—wavelength range 400—700 nm where normal aversion response (blinking) offers adequate protection
- Class 2M (Magnifier)—as for 2 but viewing of output may be more hazardous if user employs optics within the beam
- Class 3R (Restricted)—wavelength range 302.5—106 nm where direct intrabeam viewing is potentially hazardous, but risk is lower than 3B
- Class 3B—normally hazardous when intrabeam exposure occurs. Viewing diffuse reflections is normally safe
- Class 4—lasers that can produce hazardous diffuse reflections. They may cause skin injuries and could also constitute a fire hazard. Use requires extreme precaution

Lasers are used in opencut and underground mining, petroleum, and gas, and with the use of explosives. For example, lasers are used for measurement, surveying, alignment, laser scanning systems, blast design, laser cutting, and drilling.

The main risk from exposure to lasers is the potential for effects on the eye from either directly viewing the beam or from its reflection off a mirrored surface. Burns to the skin are also possible from high power lasers [15]. The risk of eye or skin damage depends on the wavelength, intensity, and duration of exposure. Laser radiation is mainly optical with relatively shallow penetration, except for Class 4 lasers [15].

16.3.5 UV radiation from natural and artificial sources

Solar radiation is the highest-energy form of non-ionising radiation, with its ultraviolet (UV) component being the greatest risk. UV radiation exists in three bands from highest to lowest energy as follows:

- Far, short of UV-C wavelengths 100-280nm and frequencies around 10^{16} Hz. Below 180nm wavelengths are absorbed by air and therefore of little significance in terms of human exposure. UV-C is therefore often defined as 180-280nm
- Middle, erythemal or UV-B wavelengths 280-315nm and frequencies around 10^{15} Hz
- Near, long or UV-A wavelengths 315-400nm and frequencies around 10^{14} Hz [16]

Apart from the sun, artificial sources of UV radiation in the resource sector may include plasma torches, and gas and electric arc welding. UV lamps may also be a source of exposure such as black lights used for non-destructive testing (UV-A), and lamps for germicidal uses (UV-C and UV-B). UV light sources with wavelengths below 250nm can interact with the workplace atmosphere producing ozone, oxides of nitrogen and phosgene [16].

Worker's skin and eyes are the main target organs for both acute and chronic health effects from UV exposure [17]. Acute effects include sunburn from solar UV and conditions such as 'arc-eye' (a sensation of sand in the eyes caused by excessive UV exposure to the eye) from arc-welding [15]. Exposure to UV radiation is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) [1]. The classification relates to its causal involvement in melanoma and non-melanoma skin cancers, including squamous cell carcinoma [1]. UV radiation can also cause damage to the lens of the eye resulting in keratitis and cataracts [15]. UV from welding processes is also classified as a Group 1 human carcinogen by IARC due to risk of skin and eye cancer.

The Australian population has the highest rate of skin cancer in the world [18]. More than 3600 people are estimated to be diagnosed with melanoma in Queensland each year [18]. Melanoma is the second most common cancer in men and the most common in women [18]. There is growing evidence that sun exposure later in life continues to add to the risk of developing melanoma [19]. The incidence of melanoma increases with age much more in men after 40–50 years of age and it is more than double in men than in women after 70 years of age.

Exposure to a range of natural products, pharmaceuticals, and chemicals can act as photosensitisers that can increase the sensitivity of skin to UV exposure (e.g., coal tar pitch, and some plant products) [15].

It is important to note that exposure to UV radiation from the sun has some beneficial effects such as sunlight being necessary for the natural production of vitamin D, which is required for healthy bones [15].

Solar UV radiation exposure occurs year-round in most sectors within mining, petroleum and gas, and explosives. Those with roles requiring outdoor work on a regular basis are most exposed. Outdoor workers in Queensland are particularly at risk and it has been estimated they receive on average approximately twice as much ultra-violet radiation UVR over a two-day period as school children or at home workers [2].

A range of outdoor activities expose workers to solar UV radiation in open-cut mines, quarries, mining exploration sites, petroleum and gas exploration, drilling, and processing sites. The depletion of the ozone layer is also increasing the amount of natural UV radiation reaching the Earth's surface and therefore increasing the risk of exposure [17].

According to the RSHQ *Mine safety bulletin no.93 07 January 2010 Sunlight and other ultraviolet radiation risk management,* the following groups have a risk of exposure to solar UV radiation:

- Exploration and Drilling—very high-risk potential. Exploration and drilling sites are often located in areas that have extreme exposure to UV with limited shade.
- Opencut Mining and Quarrying—high-risk potential. Most operational groups will have exposure. As well as exposure at work, fly in/fly out miners may be exposed at camp during the day while not at work.
- Underground Mining—low-risk potential. Many underground workers will have limited exposure. However, other groups may be at risk, such as maintenance workers and others who spend only some of their time underground, as well as workers at the processing plant, maintenance workshops and other areas.

Workers can be exposed to solar UVR from three main sources:

- Directly from the sun
- Scattered from the open sky
- Reflected from the environment [20]

Even if a worker is shaded from direct sun, they can still receive a substantial exposure from the open sky and reflective ground surfaces. If a worker is in the shade but can see blue sky, they are still exposed to solar UVR from the sky. A highly reflective environment can also increase UVR levels [20]. Some ground and building surfaces such as white paint, light coloured concrete, and metallic surfaces, are quite reflective and can reflect UVR onto the skin and eyes [20].

Workers who spend a significant amount of time during the day in a vehicle can also receive high levels of solar UVR [20]. Controls such as laminated front windscreens and tinting of the side and rear windows can greatly reduce the amount of UVR entering the vehicle. Most automotive tints provide excellent protection against solar UVR [20].

Artificial UV radiation exposure may occur with workers (as well as bystanders and passers-by) who use the following devices:

- Plasma torches
- Gas and electric arc welding
- UV lamps:
  - Such as black lights used for non-destructive testing (UV-A)
  - Lamps for germicidal uses (UV-C and UV-B)
  - UV lamps used in determining the quality of mineral deposits such as Scheelite

16.4 Current regulatory requirements for non-ionising radiation

16.4.1 General requirements

ARPANSA publishes Fundamentals, Codes and Guides in the Radiation Protection Series (RPS). To the extent possible the publications give effect in Australia to international standards and guidance from sources such as the International Commission on Radiological Protection (ICRP), the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the International Atomic Energy Agency (IAEA), and the World Health Organisation (WHO)[21].

ARPANSA's 'Fundamentals' set the core principles and are written in an explanatory and non-regulatory style[21]. The 'Codes' are regulatory in style and may be referenced by regulations or conditions of licence[21]. The 'Guides' provide recommendations and guidance on how to comply with the Codes or apply the principles of the Fundamentals[21].

The following ARPANSA Fundamentals, Codes and Guides may apply within the resources sector to the management of non-ionising radiation:

- RPS S-1 Standard for Limiting Exposure to Radiofrequency Fields—100 kHz to 300 GHz 2021

- RPS No. 12 Radiation Protection Standard for Occupational Exposures to Ultraviolet Radiation 2006

16.4.2 Mining

The only mention of radiation in the *Coal Mining Safety and Health Regulation 2017* is section 96(c)(iii) Miscellaneous, which requires a coal mine to have a standard operating procedure for laser emission and other sources of harmful electromagnetic radiation, including solar radiation.

UV radiation is a documented hazard in the *Mining Hazards Database* and therefore there should be a risk assessment for UV radiation undertaken at each site in accordance with the Regulation.

The *Mining and Quarrying Safety and Health Regulation 2017* covers non-ionising radiation as follows:

- Section 145: If a person could be exposed to radiation above acceptable limits, the site senior executive must ensure the mine has a system to provide for the safety management of the radiation and that the system is complied with.

The following guides and notices are relevant to the management of potential exposures to non-ionising radiation in Queensland mining:

- *Guidance Note QGN10 Handling explosives in surface mines and quarries*
- *Guidance Note QGN11 Handling explosives in underground mines*
- *Mine safety bulletin no.93 07 January 2010 Sunlight and other ultraviolet radiation risk management*
- *Mine safety bulletin no. 81 18 July 2002 Exposure to UV radiation from mercury vapour lamps*

16.4.3 Petroleum and gas

The QLD *Petroleum and Gas Production and Safety Act 2004*, Chapter 9 Safety, does not specifically deal with the management of radiation exposures related to Operating Plant.

16.4.4 Explosives

There is no specific mention of radiation in either the *QLD Explosives Act 1999* or *QLD Explosives Regulation 2017*. Management of the risks associated with this hazard related to the use of explosives would be governed under the relevant health and safety related legislation for the site.

16.5 Exposure standards for non-ionising radiation

This section of the report outlines exposure standards for the various types of non-ionising radiation.

16.5.1 Radio frequency radiation

The exposure standards for non-ionising radiation in the form of radiofrequency (RF) electromagnetic fields of 100 kHz to 300 GHz are detailed within ARPANSA's *RPS S-1 Standard for Limiting Exposure to Radiofrequency Fields—100 kHz to 300 GHz (2021)[22].* The standard includes levels for occupationally exposed persons (for example, workers who maintain or repair radio towers, which could be applicable to mining sites requiring radio towers for their communications) and the general public. Most workers in the resources sector would be deemed to be non-occupationally exposed (as defined by the standard) and the exposure limits set for the general public would apply.

16.5.2 Solar UVR exposure limit

The Australian exposure limit for UV radiation is established by ARPANSA within *RPS No. 12 Radiation Protection Standard for Occupational Exposures to Ultraviolet Radiation (2006)[20].* The exposure limit for both general and occupational exposure to solar UVR incident upon the skin or eye is 30 J/m^2 (joules per square metre). The 30 J/m^2 is the total calculated over an 8-hour working day. The exposure limit applies to unprotected skin and eyes. The exposure limit is intended to be used as a guideline only for solar UVR exposure [20].

The commonly referred to Solar UV Index[23], which is a measure of the maximum daily UVR, provides the public with a numerical indication of the maximum potential solar UVR level during the day. The higher the number the higher the solar UVR hazard [20]. Table 30 provides a comparison of the UV Index with the maximum time taken for an individual with unprotected fair skin to exceed the exposure limit for UVR. The higher the UV Index the shorter the time to exceed the exposure limit.

Table 30: Comparison between the UV Index and time taken for a person with unprotected fair skin to exceed the Exposure Limit (Tmax) [20].

UV Index	Tmax (mins)
3	26
4	20
6	13
8	10
10	8
12	7
14	6
16	4

16.5.3 Artificial UVR exposure limits

The exposure limits for artificial UVR are detailed within Schedule 1 of RPS No. 12 and are based on the wavelength. Table 31 below provides some examples of permissible exposure times based on Schedule 1 of the Standard.

Table 31: Some artificial sources of UVR and the times taken to exceed the exposure limits provided within Schedule 1 of the ARPANSA RPS No. 12 [20]

Category	Exposure Time
Fluorescent lamp	>8hrs
Quartz halogen lamp	~ 10 mins
UVA lamp	~ 17 mins
Germicidal (UVC) lamp	1-3 mins
Arc Welder	1-5 mins

16.6 Measurement and evaluation of the hazard

16.6.1 Extremely Low Frequency (ELF) radiation

A magnetic field meter can be used to measure the strength of magnetic fields generated by the passage of mains electricity. The magnetic field meter is a small hand-held device with a digital display that reads in units of milligauss (mG). The magnetic field meter is suitable for measuring magnetic fields from electrical infrastructure (e.g., powerlines, substations) and electrical appliances (e.g., toaster, hair dryer).

16.6.2 Solar UV radiation

One of the main problems with measuring solar UVR is the lack of available and adequate methods to estimate UV worker exposure, especially long-term exposure [17]. However, there are simple UV Index meters, which are small hand-held devices with a digital display of the UV index reading. These devices are suitable for conducting spot checks only and do not estimate exposure over time.

There are a number of emerging technologies for personal monitoring of UV exposure, including smart devices with applications that can calculate an estimate of the UV dose received by a worker [24-26], wearable self-powered photodetectors (UV radiation sensor) that transmit data to smartphones [27],

16.6.3 Artificial UV radiation

Assessment of the UVR hazards from artificial sources can be achieved in a number of ways[20]:

- Obtaining information on the source emissions and power allows an initial assessment of potential hazards. This information can be obtained from the manufacturer’s data sheets, which can list the spectral output or the amounts of UVA, UVB and UVC.
- Dosimetric assessment using UVR sensitive polysulphone film can give an indication of the presence of hazardous UVR. If the source spectrum is known, then the hazard can be accurately assessed.
- Radiometric or spectral assessment of the source output can provide the information to accurately quantify the amount and type of UVR mitted and thus allow calculation of the hazard.

16.7 Summary of non-ionising radiation exposure data currently available to RSHQ

16.7.1 Documents provided that included data related to non-ionising radiation

- Lost Time Injury Data (2011 to 2020)
- Accepted Workers' Compensation Disease Claims (Accepted claims lodged between 1 July 2016 and 31 December 2020) for mining
- Health Risk Assessments for individual sites
- Mines safety alert no. 81, 18 July 2002, Version 1 Exposure to UV radiation from mercury vapour lamp

16.7.2 LTI data

There were four (4) reported lost time injuries related to non-ionising radiation exposure over the period 2011 to 2020. Injuries included:

- A Sampler suffered an acute exposure to solar UV radiation resulting in heat-related illness (Open Cut Mineral Mine)
- Electrician burned from exposure to arc flash x 2 (Underground Mineral Mines)
- Technician suffered an eye irritation caused by UV light from a Tracerline UV Light (Underground Mineral Mine)

16.7.3 Workers' compensation data

The accepted workers' compensation disease claims data for the period 1 July 2016 and 31 December 2020, includes four (4) specified claims for the mechanism of exposure to non-ionising radiation, including:

- Three (3) claims for exposure to arc-welding resulting in diseases of the conjunctiva and cornea
- One (1) for solar UV exposure resulting in malignant melanoma of the skin

The three claims for arc-welding were all from open cut coal mining and the solar UV claim was from the industry classification of 'other construction material mining'.

16.7.4 Health Risk Assessments (HRAs)

The Health Risk Assessments provided included reviews completed for specific sites, including coal mines (3 reports), metalliferous mines (1 report), and petroleum and gas drill rig sites (6 reports). Non-ionising radiation was briefly listed as an occupational health hazard in most of the HRAs, especially UV radiation from the sun and from arc-welding. None of the reports included any specific quantitative data on non-ionising radiation exposures.

16.7.5 Mines safety alert no. 81

The Mine Safety Alert number 81 from 18 July 2002 described an incident involving the use of a Mercury Vapour Lamp as follows: "Five lost time injuries with nine days lost time occurred after a group of mineworkers working to remove a rock from a ROM sizer were exposed to short-wave ultraviolet radiation being emitted from a 400W mercury vapour lamp situated directly above the site of work. The outer envelope of the lamp had broken but the lamp continued to discharge. The workers were treated for skin burns and eye ash burns. Some workers had noticed that the lamp cover and lens on the fitting were broken prior to work, but not recognising the hazard decided it could wait to be changed. Prior to the incident the lamp regularly failed due to mechanical impact—about once a month. If the outer envelope of a mercury vapour or metal halide lamp is broken the lamp should not be operated with the arc tube exposed due to the potential for emission of harmful UV radiation." The notice also advised that "lamps that will automatically extinguish when the outer envelope is broken or punctured are commercially available."

16.8 Status of the data available to RSHQ

The non-ionising radiation exposure data provided by RSHQ consists of some LTI reports and accepted workers' compensation disease claims combined with minimal qualitative information. More data is needed to be able to evaluate the magnitude and variability in exposures in the Queensland resources sector to non-ionising radiation, and the hazard is presently likely to be underestimated. Of particular concern is exposure to solar UV radiation for outdoor workers.

16.9 How could data collection and management be improved?

It is recommended that organisations within the Queensland resources sector be encouraged to include potential non-ionising radiation exposures in their health risk assessments, including quantitative assessments of workers' exposures to solar UV radiation.

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Polymeric chemicals

17. Polymeric chemicals

17.1 Overview

Summary of the health effects presented by the risk
► Some polymeric chemicals are carcinogenic ► Most cause acute irritation to the eyes, respiratory tract, and occupational asthma
What we know about the risk (available data and evidence from RSHQ and other sources)
► Data could not be provided by RSHQ to evaluate the level of risk. The granularity of the Workers' Compensation data did not permit identification of any polymeric chemical related diseases. ► The only HPI reported did not relate to an incident rather to a potentially inadequate analysis technique. ► Companies using polymeric chemicals are required to manage them in accordance hazardous chemical sections of the CMSHR and MQSHR for mines and quarries, and WSHR for other work sites and Recognised Standard 16 for underground coal mines. ► Previous testing, undertaken by safety in mines testing and research station (Simtars), has identified the potential for release of a range of airborne contaminants from neat polymeric products, and during the mixing and curing process. ► In 2020, a project was initiated by RSHQ to review the adequacy of three current air and analytical monitoring techniques. Data drawn from this project is not yet at a point where it could be shared more broadly to inform the baseline review of occupational health risks. However, it is important to acknowledge the work going into understanding this emerging risk (RSHQ, 2021).
How we can learn more about the impact of this risk in the resources sector in Queensland
It is recommended that targeted assessments of individual mine usage of polymeric chemicals be undertaken to ensure compliance with regulation. Access to mine biological monitoring and personal exposure monitoring data should be sought. This is important as Safe Work Australia have recently recommended a reduction in the exposure standard from 0.02 mg/m^3 to 0.0001 mg/m^3. In addition, it has become evident that a major potential path of contamination is through the skin rather than breathing in an aerosol.

There are a wide variety of polymeric materials used in the mining, and gas and petroleum industry. These include polyurethanes (PUR) that are widely used in paints, sealants and as foams to fill cracks and provide structural support in underground mines. PUR has also been used to fill tyres.

According to Leading Practice Handbook: Hazardous Materials Management (*Leading Practice Sustainable Development Program in the Mining Industry, Sept 2016*), some polymeric compounds that are approved for use in mining are: polyurethane (PUR), urea silicate, and phenolic resins.

17.2 What is the health hazard?

Table 32: Common polymeric compounds and associated health hazards

Compound	Health hazard component
Polyurethane	Contains methylene diphenyl diisocyanate (MDI) or Toluene Diisocyanate
Urea silicate	Contains methylene diphenyl diisocyanate (MDI)
Phenolic resins	Contains phenol and formaldehyde. Phenol is a highly corrosive and toxic substance that can enter the body through inhalation, ingestion, and skin absorption.

Table 33: Commonly encountered polymeric chemicals

Name	Form	Main uses
Toluene diisocyanate (TDI)	Liquid	Flexible polyurethane foam production
Methylene diphenyl diisocyanate (MDI)	Low- melting point solid	Rigid polyurethane foam production
Naphthalene diisocyanate (NDI)	Solid	Elastomers and synthetic rubbers
Hexamethylene diisocyanate	Liquid	Spray paints (including 2 pack paints), lacquers and car re-finishing
Methyl isocyanate (MIC)	Liquid (highly volatile)	Intermediate in the production of some pesticides
Isophorone diisocyanate (IPDI)	Liquid	Manufacture of coating and adhesive polymers and polyurethane foams
urea silicate	Liquid Contains methylene diphenyl diisocyanate (MDI)	Used for strata consolidation, water control and rock/cable bolt grouting.
phenolic resins	Liquid Contains phenol and formaldehyde.	Used in coatings and adhesives

(Safe Work Australia, 2020).

17.3 What are the health effects/consequences of exposure?

Table 34: Polymeric chemicals – Consequences of exposure

Hazardous Compound	Consequence
Polyurethane (PUR)	Exposures to isocyanates are known to cause health effects ranging from: ► Acute irritation of the respiratory tract to permanently debilitating respiratory conditions, difficulties breathing, tightness of chest, coughing, wheezing and shortness of breath ► Occupational asthma and asthma like symptoms ► Headache and discomfort ► Allergic dermatitis ► TDI and IDPI have been determined to be a potential human carcinogen by IARC and the WHO. (Safe Work, 2020)
Urea silicate	Exposures to isocyanates are known to cause health effects ranging from: ► Acute irritation to permanently debilitating respiratory conditions difficulties breathing, tightness of chest, coughing, wheezing and shortness of breath, ► Occupational asthma ► Headache and discomfort ► Allergic dermatitis

Hazardous Compound	Consequence
	► TDI and IDPI have been determined to be a potential human carcinogen by IARC and the WHO. (Safe Work, 2020)
Phenolic resins	Acute irritant effects and systemic toxic effects: ► Formaldehyde is highly irritating to the eyes, nose, and throat ► Systemic toxic effects due to high exposure include central nervous system impairment and liver and kidney damage

Skin absorption represents the greatest risk of exposure for mine workers for many of these hazardous compounds due to close contact of the worker and the methods of application of the chemical, e.g. painting. For that reason, biological monitoring is the preferred method for assessing exposure.

The polymerisation process is exothermic which leads to the volatilisation of any unreacted components.

17.4 Who is exposed? And how are they exposed?

Most large-scale use of PUR occurs in underground coal mines as a strata binding/filling agent. The guide produced by Safe Work Australia, *Guide to Handling Isocyanates,* provides a comprehensive list of occupations that may be exposed to isocyanate across all industries (Safe Work Australia, 2020).

In general, the most at-risk categories are:

- Workers undertaking void filling—dermal contact with materials and inhalation of fumes or workers downwind of them inhaling the fume
- Maintenance personnel engaged in tyre maintenance—mainly through inhalation of dusts, but also fume from the use of PUR in tyre filling
- Workers applying paints, coatings, or adhesives—both through inhalation of fume and dermal contact with materials
- Welding interacting with PUR foam lagging releasing vapour
- Application or removal of varnishes that contain PUR
- Application of two-pack paints, lacquers, adhesives, and vinyl wrapping and cutting into or grinding or heating them up

17.5 What are the current QLD regulatory requirements for the management of the hazard?

Polymeric Chemicals are classified as hazardous chemicals by Safe Work Australia and under the CMSHR 2017 and MQSHR 2017 due to their GHS classification, and as such are covered by the appropriate sections of the CMSHR 2017, MQSHR 2017 and WSHR 2011.

Part 7 of the CMSHR 2017 and the MQSHR 2017 describes Hazardous Chemicals and Dangerous Goods. The subdivisions and sections describe:

- The meaning of hazardous chemical and dangerous goods
- The need for the SSE to maintain a register of hazardous chemicals and dangerous goods

- The requirements for manufacturers, suppliers, and importers to mark and label substances
- The need for the SSE to ensure that hazardous chemicals and dangerous goods are correctly marked and labelled
- The SSE must ensure that a hazardous chemical or dangerous good selected for use at the mine does not create an unacceptable level of risk to a person when used, handled, or stored under standard work instructions
- The SSE must ensure that the mine has standard work instructions (SWI) for using, handling, or storing hazardous chemicals or dangerous goods
- The risk at a mine relating to the handling or storing of a hazardous chemical or dangerous good must be managed
- The SSE must ensure that appropriate monitoring in relation to a hazardous chemical or dangerous goods is carried out as part of any SWI or other procedure that applies to monitoring
- The SSE must ensure that the mine has a SWI for dealing with leaks and spills
- The SSE must ensure that the mine disposes of hazardous chemicals or dangerous goods appropriately

Exposure to hazardous chemicals that causes or has the potential to cause a significant adverse effect on the safety or health of a person is classified as a high potential incident under CMSHR 2017 Schedule 1C and MQSHR 2017 Schedule 1. No HPIs have been reported in the data supplied by RSHQ relating to these chemicals.

Division 3 and subsidiary sections of the MQSHR 2017 outline the requirements for health surveillance for the non-coal mining sector. Health surveillance is required if the SSE reasonably believes or ought to reasonably believe that exposure to a hazard at the mine may cause or result in an adverse health effect under the worker's work conditions and either there exists a valid technique capable of detecting signs of the health effect, or a valid biological monitoring procedure is available to detect the changes from the current accepted values for the hazard. S139 describes the requirements to remove any affected worker from the work environment. S140 describes the use of PPE to manage the exposure if a mine cannot prevent or reduce the exposure by other means.

Subdivision 3 of Division 2 of the CMSHR 2017 describes the requirements for the Coal Mine Workers' Health scheme. S49 specifically requires that the mines Safety and Health Management System must provide for periodic monitoring of the level of risk from hazards at the mine from hazards that are likely to create an unacceptable level of risk. It also requires the employer to ensure that the worker's exposure to the hazard is periodically monitored to assess the level of risk to the worker if the worker is exposed to a hazard at a coal mine that may increase the level of risk. CMSHR—1 Health assessment form lists under question 1.5 Specific coal mine worker position requirements or hazard exposures section (c) Coal mine worker may potentially be exposed to a list of specific hazardous chemicals including:

- Oils, greases
- Solvents
- Phenols

- Isocyanates
- Acids
- Alkalis
- Cement, grout, stone dust
- Detergent, hand cleaners
- The medical examination includes assessment of the skin, respiratory examination, spirometry, and x-ray

Schedule 1C lists a number of notifiable diseases mainly relating to respiratory issues but also including cancers (Schedule 1 in the CMSHR 2017). Schedule 5 refers to general exposure limits for hazards deferring to the National Occupational Health and Safety Commission (NOHSC, 1985-2005) document—Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995). Note this document has been superseded by the Safe Work Australia Workplace Exposure Standards for Airborne Contaminants, last issued 2019 (presently undergoing review).

Recognised Standard 17 Recognised Standard for Hazardous Chemicals under the CMSHA 1999 is a comprehensive document aimed at assisting coal mines in managing the risks associated with hazardous chemicals. Its contents include:

- Classification and labelling of workplace hazardous chemicals
- Manifests and placarding of hazardous chemicals and dangerous goods
- Preparation of safety data sheets (SDS) for hazardous chemicals
- The content of the SDS including
- Hazard identification
- Composition and information on ingredients
- First aid measures
- Firefighting measures
- Accidental release measures
- Handling and storage
- Exposure controls and personal protection
- Exposure control measures
- Biological monitoring
- PPE
- Physical and chemical properties

- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information

QGL03 – Guideline for Hazardous Chemicals (July 2019) issued by the then Department of Natural Resources, Mines and Energy outlines the processes for safe acquisition, storage and use of hazardous chemicals in general under the MQSHA 1999. This mirrors RS-19. The controls required depend upon the specifications outlined in the safety data sheets (SDS) supplied for the hazardous chemical. It is therefore vital that the SDS are accurate and comprehensive enough to permit effective management of the risk. Chapter 11 of the guideline outlines these requirements. It lists in excess of 120 groups of substances or families, that should be used to ensure consistent labelling of hazardous chemicals.

Exposure to hazardous chemicals not on mine sites or at quarries is managed under the Work Health and Safety Regulation 2011 for non-mine sites. Schedule 14 of this regulation outlines the requirements for health monitoring (Division 6, sections 368 to 378) for a range of chemicals

Health monitoring requirements may include:

- Demographic, medical and work history
- Records of personal exposure
- Physical examination with emphasis on areas where chemical has impact e.g. respiratory system, peripheral nervous system, or skin
- Urinary/blood analysis

Form 28 Hazardous chemical health report outlines the reporting requirements for any person being assessed for potential adverse health effects due to hazardous chemicals. This form must be sent to WHSQ.

In 2013 WHSQ issued a code of practice for managing the risks associated with hazardous chemicals in the workplace. This document aligns with the Safe Work Australia code of practice described below (WHSQ, 2013).

In 2007 RSHQ issued a safety bulletin (no.74) on Isocyanates from 2-pack paints and use of polyurethane resins in mining. This document aimed to promote awareness of the risk posed by the uncontrolled use of 2-pack paints and ways to control the hazard. It also addressed the issue of isocyanates and polyurethane resins as used in underground coal and metal mines, particularly to fill the tyres of free steer vehicles.

The bulletin discussed the use of polyurethane for strata binding associated with longwall operations. It outlines the requirements for health surveillance monitoring to protect the workers exposed to isocyanate. The bulletin points out that wherever polyurethane is used a risk assessment must be carried out in accordance with MQSHR 2017 and that a fire retardant has been added to the chemicals given the exothermicity of the polymerisation process. The controls identified included:

- Proper induction and training in the health hazards
- Following safety instructions provided on the material safety data sheets
- Conduct air monitoring to measure the airborne concentrations of isocyanates and help assess the effectiveness of control measures
- Wear gloves and full-face air-supplied respirator during spraying. Also wear gloves during clean up
- Ensure mixing area is well ventilated
- Arrange a designated doctor to provide ongoing health surveillance for workers who may have been exposed to significant risk

RSHQ has issued Recognised standard 16 (v2—2020): The use and control of polymeric chemicals at underground coal mines and guideline QGL03 (2019) Guideline for Hazardous Chemicals. The recognised standard outlines the requirements for health surveillance and biological monitoring consistent with Safe Work Australia Isocyanate Health Monitoring (Safe Work Australia, 2020a).

The recognised standard outlines in detail the requirements for the development of a procedure for the storage and use of polymeric chemicals based upon risk management processes. The procedure will consider and document:

- Preventing the use of inappropriate chemical formulations
- Mixing of incompatible products
- Ensuring these products are only applied by trained and competent coal mine workers
- The ventilation quantities and plan
- Any atmospheric monitoring requirements (refer to Appendix 4 of RS16)
- Details of the zones of operation (ZOO) and restricted access zones (RAZ) and how these will be controlled
- General arrangement illustrations for equipment set up locations
- Volumes of product injected and hole spacing. Note: Volumes not to exceed quantities specified in Table 1 of the recognised standard
- Personal protective equipment requirements
- Ensuring systems are in place to monitor the health of coal mine workers
- Spillage and emergency response requirements

- Communication plan

Table 35: Table 1 from Recognised Standard 16 – Use and control of polymeric chemicals

Table 1 of Recognised Standard: Quantity (kg) of injection resins not to be exceeded per injection hole. Polymeric injection chemical	Maximum quantity to be injected per hole (kg)
Phenolic injection resins (excludes phenolic cavity fillers)	600 kg
Polyurethane (PUR) injection resins	200 kg
Urea silicate injection resins	400 kg
Pumpable resin grouting systems	400 kg

With regard to the training requirements mentioned in Safety Bulletin no.74 There are five specific Nationally Accredited units of competency relating to the storage and use of polymeric chemicals in underground coal mines.

RIIMCU409—Apply and monitor polymeric chemical management plans
RIIMCU312—Conduct polymeric chemical operations in underground coal mining
RIIMCU313—Mix and pump polymeric chemicals in underground coal mining
RIIMCU314—Transport and store polymeric chemicals in underground coal mining
RIIMCU218—Work safely with polymeric chemicals in underground coal mining

RSHQ provided an example of a de-identified Hazard Management Plan from an underground coal mine—Use of Polymeric Materials. The key structure of the document was:

- Risk Summary—It was based upon a risk assessment carried out in 2019.
- Chemical testing to ensure compliance with MDG3608 and Ansberg Test
- Training – competency + awareness for all coal mine workers
- Plant and equipment – in accordance with NSW MDG 41
- Inspection and maintenance
- Storage and disposal
- Application
- Restrictions – where the polymeric chemicals are not to be used
- PPE
- Health effects
- Health surveillance and biological monitoring
- Atmospheric monitoring

- Workplace inspections
- Competencies and Authorisations
- Roles and Responsibilities
- Records
- Internal References
- External References
- Review criteria
- Record of Consultation
- Document Control

It references phenolic resins, urea silicates and polyurethane resins. It outlines the requirements for health surveillance, prior to, and during undertaking any work with polymeric chemicals. In addition, the health surveillance medical should be undertaken at the completion of the work, or at six weeks and then six-monthly intervals for workers undergoing continued exposure. Further it goes on to describe the required biological monitoring regime which was random (1 in 5) post shift urine testing.

17.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Safe Work Australia have issued a code of practice for managing the risks of hazardous chemicals (*Safe Work Australia, 2020*), as well as supporting documentation including the Exposure Standard Documentation for Isocyanates as part of the *Hazardous Chemical Information System (HCIS, 2021)*. This sits under the *Model Work Health and Safety Regulations (Hazardous Chemicals) Amendment 2020*.

In NSW, the polymeric process in underground coal mines is a licensed process, and the licence must be approved by the Resource Regulator prior to use (RR,2021)—Clause 152 (3) of the *Work Health and Safety (Mines and Petroleum Sites) Amendment Regulation 2018*.

In WA, the Commission for Occupational Safety and Health (part of the Department of Commerce) issued a guidance note for "Controlling isocyanate hazards at work" in 2008. The guidance note is structured:

- Who is at risk?
- How can isocyanates harm you?
- Which WA workplaces have the highest risk?
- What are the different isocyanates?
- What are the other isocyanate hazards?
- What information and training is required?

- What are Material Safety Data Sheets (MSDS)?
- How can isocyanate hazards be controlled?
- What storage controls are necessary?
- What are the specific requirements for isocyanates?
- What first aid facilities should be available?
  What is the law?
- Further information.

This document is aimed at general industry not the resources industry, though the risks and controls are relevant to its use.

17.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

Safe Work Australia Exposure Standards (as at 2021) (HCIS, 2021)

Table 36: SWA exposure standards for ingredients found in polymeric chemicals

Workplace exposure standards for individual chemical ingredients in polymeric chemicals	TWA (mg/m^3)	STEL (mg/m^3)	Proposed (mg/m^3)	ACGIH (mg/m^3)	NIOSH (mg/m^3)	OSHA (mg/m^3)
MDI and PMDI	0.02	0.07	0.0001	TLV 0.02 STEL 0.07	TLV 0.02 STEL 0.08	PEL 0.08
Phenol	4	-	4	TWA 19	TWA 19 STEL 60	TWA 19
Formaldehyde	1.2	2.5	0.12 STEL 0.37	TWA 0.37	TLV 0.02 STEL 0.12	TLV 0.9 STEL 4.5

PUR exposure is based upon the isocyanate (NCO) concentration in the sample.

- OSHA proposed a TLV of 0.005 ppmv and STEL of 0.02 ppmv for isocyanates was overturned by court order following appeals by various industry organisations.

Some of the isocyanates have had IDLH values determined by NIOSH:

- MIC 3 ppmv
- MDI 75 mg/m^3
- TDI 2.5 ppmv

The biological testing requirements are outlined in Table 37 of Recognised Standard 16 as set out below. The frequency of monitoring shall be risk based, the monitoring program should be reviewed and approved by a person with relevant experience and qualifications such as a certified occupational hygienist (COH) and/or an occupational physician.

Table 37: Guideline biological exposure limits for polymeric chemical ingredients

Polymeric Chemical Group	Ingredient	Test	BOEL / BMGV
Polyurethane resins (PUR)/ Silicate resins	MDI / PMDI*	Urinary isocyanate metabolites	1µmol of isocyanate-derived diamine/ mol creatinine in urine (a)
Phenolic resins and cavity filler	Phenol	Urinary phenol	2.1 mmol/ L (b)

Notes about this table.

a. This value is a Biological Monitoring Guideline Value (BMGV)

b. This value is a Biological Occupational Exposure Limit (BOELs)

17.8 How is the hazard measured/evaluated in the workplace?

Current method and its limitations:

There are no Australian Standard Methods for Polymeric chemical monitoring. The NIOSH methods are commonly used.

NIOSH (USA) standard methods:

- NIOSH method 5525—isocyanates-total-glass impinger method sample, depending on concentration of isocyanate. Analysis by HPLC, Fluorescence detector/UV detector
- NIOSH method 5522—isocyanates, individual components liquid impinger Analysis by HPLC, Fluorescence detector/electrochemical detector
- NIOSH method 5521—isocyanates, monomeric, individual components liquid impinger Analysis by HPLC, UV detector/electrochemical detector (*NIOSH Manual of Analytical Methods, Fourth edition, 1994*)

Chapter K of the *1998 NIOSH Manual of Analytical Methods* details the determination of airborne isocyanate exposures. It describes the challenges in sampling and analysing for isocyanates. The problems are outlined as:

- During collection—need to collect both vapours and aerosols. There can be problems with collection efficiency.
- Derivatization—isocyanate species are reactive and must be stabilized by converting them to stable derivative compounds; this requires the collection medium to trap all the isocyanate and to ensure that it completely reacts with the reagents.
- Sampling—field trials of bubblers indicate that they are more efficient than coated impingers.
- Sample handling and preparation—Some collection medium must be protected from light as the reagents are light sensitive, have limited shelf life and storing in freezers.
- Separation—separation into individual isocyanate components usually by HPLC (high-performance liquid chromatography). This technique requires the elution efficiency to be optimised against separation of components.

- Identification—based upon retention time of eluent on HPLC. Elution times are generally only available for the monomers and if any has polymerised then it will not be detected. Similarly, UV and EC detectors do not characterise the component detected merely that a component has been detected.
- Quantification—Assuming the peak on the HPLC has been completely identified, it can be integrated to give the concentration present. It is imperative that the peak is greater than the limit of detection and less than the saturation point. In some cases, this range may only be two orders of magnitude.

OSHA offer methods:

- 32—Phenol and Cresol using analytes are collected on an XAD-7 sampling tube and desorbed with methanol. The analysis is performed by HPLC with ultraviolet (UV) detection at 218 nm.
- 42—for TDI using a coated glass fibre filter followed by extraction and HPLC.
- 47—for MDI using a similar method.
- 1007—Formaldehyde—Diffusive samples are collected by exposing either Assay Technology ChemDisk Aldehyde Monitor 571 (ChemDisk-AL), SKC UMEx 100 Passive Sampler (UMEx 100), or Supelco DSD-DNPH Diffusive Sampling Device (DSD-DNPH) to workplace air. Samples are extracted with acetonitrile and analysed by LC using a UV detector.
- 52—Formaldehyde—using a XAD-7 packed column for absorption and analysis as above.

Safe Work Australia have issued a guide for *Health Monitoring of Isocyanates (2020)*. This relates specifically to medical surveillance monitoring, not workplace exposure standards. Where workers are exposed or suspected of being exposed or are concerned about exposure to isocyanates the PCBU should arrange for a health monitoring appointment with a registered medical practitioner. Workers should undergo a medical examination at 6 weeks from the start of the health monitoring program and then at six monthly intervals during continued exposure. If there is no evidence of adverse health effects this interval can be extended to twelve months. Urinary testing should be undertaken as part of the medical assessment.

17.8.1 Emerging technology/research

An alternative to the above methods is the use of passive chemical badges for screening purposes. The badge must be attached within the breathing zone of the individual. Badges are available for volatile components such as phenol and formaldehyde. The samples are processed as per the above NIOSH methods. See for example: https://sensorssafety.com/products/formaldehyde-passive-monitoring-badge-4180.

There are real time monitors for formaldehyde using electrochemical (EC) sensors e.g., the Formaldemeter (https://www.ppm-technology.com/formaldemeter htv.htm. It takes 10 mL snatch samples by pump. It typically samples every 2 minutes and responds within a minute. The default range is 0-10 ppmv with a resolution of 0.01 ppmv. Its accuracy is +/- 10 % at 2 ppm. Other ranges can be selected.

Schettgen et al (2015) developed a simple and sensitive method for determining urinary phenol, involving enzymatic hydrolysis followed by gas chromatography-mass spectroscopy (GC-MS). This has not been adopted as an industry standard.

Pala et al (2008) carried out monitoring of research workers looking at markers in blood. Correlation was found between exposure to formaldehyde and formaldehyde human serum albumin conjugate (FA-HSA). Biomarkers (that would measure an adverse health effect) did not find evidence of the presence of genetic damage.

17.9 What health monitoring data is currently available to RSHQ?

17.9.1 What is the status of the data/issues with the data?

Polymeric chemicals are used extensively in mining and construction to fill cavities, reinforce, and stabilise strata in the underground environment. Previous testing, undertaken by safety in mines testing and research station (Simtars), has identified the potential for release of a range of airborne contaminants from neat polymeric products, and during the mixing and curing process.

These contaminants include the organo-isocyanate species Phenyl-isocyanate and Methyl-isocyanate as well as 4,4'-Methylene diphenyl diisocyanate (4,4-MDI) oligomers / pre-polymers and volatile organic compounds (VOC) that in many cases are not identified using current air monitoring and analytical methods. In 2020, a project was initiated by RSHQ to review the adequacy of three current air and analytical monitoring techniques. Data drawn from this project is not yet at a point where it could be shared more broadly to inform the baseline review of occupational health risks. However, it is important to acknowledge the work going into understanding this emerging risk (RSHQ, 2021).

A health risk assessment carried out at an open cut coal mine in 2017 identified that a number of workers—mainly maintenance personnel—occasionally used small quantities of paints. The level of risk was considered low. No actual exposure monitoring information was provided in the report.

A second HRA at an open cut coal mine in 2017 did identify exposure to isocyanates as a potential health hazard with potentially major chronic consequences, though no detailed analysis was provided of the hazard and it was not assessed in the actual qualitative risk assessment.

The Health Exposure Risk Assessment carried out at a gold mine in 2017 did not identify any potential polymeric chemical exposure.

The Health Risk Assessment carried out in 2019 for the Queensland Petroleum and Gas Inspectorate at a work rig and hybrid coil drilling operation also identified the occasional use of paints by maintenance personnel as low risk.

The HRA at two biogas power generation plants carried out in 2020 did not identify polymeric chemicals as a potential health hazard.

Streicher et al (2010) identified a number of challenges to monitoring isocyanates because:

- The isocyanates may in the form of vapours or aerosols of various sizes
- The species are reactive and therefore unstable
- Pure analytical methods only exist for monomeric isocyanates
- Low limits of detection are needed
- Convenient robust methods often in conflict with need for sensitivity

They compare exposure standards and noted that NIOSH consider TDI an occupational carcinogen and recommends that exposures be reduced to the lowest feasible concentration. HSE did not specify individual TWA or STEL rather used a combined Total Reactive Isocyanate group TWA of 20 $\mu g/m^3$ and 70 $\mu g/m^3$. They point out that the US standards do not address the issue of mixed isocyanates, or poly-isocyanates having different toxicity to the monomers.

17.9.2 What does it tell us about workers exposures?

No data was provided about worker exposure, and there is no record within the workers' compensation statistics that identified any resource sector incidence of polymeric chemical related disease. There is a lack of granularity in the WC data and it is possible that some of the instances listed under other diseases such as asthma, diseases of the skin, other diseases of the respiratory system and contact dermatitis, may have been caused by polymeric chemical exposure.

There is one high potential incident (HPI) though not relating to an actual incident, but which casts doubt upon the quality of the biological monitoring being carried out for isocyanates at a mine. This indicates that biological monitoring is being undertaken by industry. Accessing this information would give a better picture of the exposure risk of mine workers to isocyanates.

17.9.3 How could data collection and management be improved?

There is no data to indicate persons are being adversely affected by exposure to polymeric chemicals. However, the quality of the data supplied by RSHQ does not permit adverse effects to be identified – as described above. RSHQ could undertake targeted assessment of biological monitoring of individuals working with polymeric chemicals—spray painters, maintainers, workers undertaking cavity filling or strata binding.

Within Recognised standard 16 it states:

The employer shall ensure that all coal mine workers who apply polymeric chemicals containing isocyanates must complete baseline health surveillance before starting work in an isocyanate process, and this evidence is to be provided to the Site Senior Executive (SSE).

Surveillance will include:

- Demography, occupational and medical history, and health advice
- Standardised respiratory function test
- Respiratory questionnaire
- Skin examination

DMIRS (WA) provide guidance on health surveillance for workers exposed to isocyanates, as part of this there is a specific health surveillance form for isocyanates that must be filled out by a medical practitioner which focusses on a questionnaire, respiratory function and includes optional biological monitoring.

17.10 What other exposure data is available/in peer reviewed literature?

17.10.1 Historical data

The papers discussed in this section illustrate the risk of exposure to polymeric chemicals can be as important through the skin as inhalation. Common respiratory symptoms include wheezing, chronic coughing, and occupational asthma. Most of the studies have been on spray painters, with no mining specific research being located.

The NIOSH website describes a number of deaths from exposure to diisocyanates over an extended period of time, (https://www.cdc.gov/niosh/docs/96-111 Preventing asthma and death from diisocyanate exposure (DHHS 2004)

NIOSH have released a number of reports evaluating the potential health hazard of exposure to MDI during the application of polyurethane foam. In one study it also investigated the potential exposure to silica and asbestos during rock dusting. They concluded that wearing effective personal protective equipment (PPE) including nitrile gloves provided effective protection and MDI as not likely to be a significant airborne hazard—this is because the application process does not aerosolize the MDI and it does not readily evaporate due to its low vapour pressure. They did not do air sampling for MDI for this reason.

Pierrehumbert G et al (2002) studied the impact of human variability on the biological monitoring of exposure to toluene, phenol, lead, and mercury, and found that toluene uptake varied significantly between individuals with the same exposure.

In a study by Creely et al (2006) of 70 samples from 22 sites, it was found that biological uptake was demonstrated to occur even when the airborne concentrations of isocyanates were very low. This suggests that either that the PPE being worn was ineffective, or there was absorption via dermal or other routes of exposure.

A paper by Piney et al (2015) reports that exposure to isocyanates is the leading cause of occupational asthma in the UK. The research focussed on reducing the exposure of spray painters using isocyanate-based paints. Airborne concentrations in spray booths historically have been up to several hundred micrograms per cubic meter in spray rooms up to thousands of micrograms/meters cubed. Monitoring the effectiveness of an intervention to reduce exposure was monitored using biological monitoring kits.

A paper by Cocker (2011) discusses the discrepancy between airborne monitoring and biological monitoring in urine or blood. Biological monitoring converts the isocyanate monomer to the diamine. Biological methods exist for HDI, IPDI, TDI, NDI, and MDI. At the time of the study only Germany and the UK were using biological monitoring guidance values, though the American Conference of Governmental Industrial Hygienists (ACGIH) was working on a biological exposure index (BEI) for TDI.

The authors point out that dermal exposure can be a significant point of entry for isocyanates, even when the airborne concentrations are negligible. The paper reports the results of several studies comparing biological data with airborne levels in occupational studies. Isocyanates in paint sprayers are present not only as monomers but also as oligomers—where the monomer has partially polymerised. It is possible that the biological testing of urine when oligomers are present may underestimate the concentration of isocyanates.

In a study of 216 miners (Lenaerts (1992) involved in rock consolidation were exposed to MDI. 8 workers were treated for MDI-pollution of the skin. 6.5% of the workers reported shortness of breath, 1.8 % reported specific bronchial hyperresponsiveness. The prevalence of isocyanate asthma was 0.9 %.

A literature review of published studies by Park (2021), concluded that for a 1 in 1000 lifetime risk excess at about 2 ppt TDI, for sensitisation and impairment (45 year working life). People can be sensitized after short term high exposure, e.g. > 25 ppb in less than two years operation. 14 out of 34 people were diagnosed with TDI-related asthma. In Another study, after six months of >10 ppb exposure, 7 out of 49 workers had asthma symptoms. Long term exposure at very low levels (<9 ppby) can result in a 1 in 100 risk of occupational asthma. At this level, TDI is detectable in urine samples. The conclusions of the study are that the OEL should be more than 100 times smaller than the current OELs.

A literature review of published studies by Daniels (2017), concluded a BMD-based OEL of 0.4 ppbv. The OEL, based upon low dose extrapolation to working lifetime extra risk of 1/1000, was 0.3 ppbv.

An analysis of mortality data (Pinkerton et al, 2016) found that compared to US general population, all cause and all cancer mortality was increased. Lung cancer was increased but not associated with exposure duration or cumulative TDI exposure. The conclusion was that dermal exposure rather than inhalational exposure to TDI may play a role in the observed increase in lung cancer mortality.

A study of underground coal miners with MDI related Isocyanate Symptoms (IS) and ureaformol/formophenolic related symptoms (UFS) by Bertrand et al (2007) found that of resin handlers 5.6% were affected. UFS affected 22.6%. Wheezing affected 35.6%, chronic cough, expectoration, or bronchitis 10%, dyspnea 5.4% and asthma 2.8%. The symptoms detected initially were allergic contact dermatitis. They noted that workers exposed to less than threshold values and with intermittent exposures, related symptoms such as asthma and contact dermatitis have been observed. Workers with respiratory symptoms and alterations in lung function, exposure to MDI or ureaformol or formolphenolic may worsen these diseases.

Biological monitoring of spray painters' urine showed that 2.6% were exposed to isocyanates and 1.0% being moderately exposed (more than twice the current UK HSE BMGV of 1 μmol per mol) (Hu et al (2017).

Fent et al (2010) explored the potential for dermal absorption of MDI. They found that workers were protected by PPE and the application was in good condition and there was no leakage. No exposure monitoring was undertaken as MDI does not readily evaporate due to its low vapour pressure and the creation of the foam does not aerosolize readily.

17.10.2 Current data

A Web of Science review did not identify any current studies of resource industry personnel potentially affected by polymeric chemicals.

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Respirable crystalline silica and other particulates (dust)

18. Respirable crystalline silica and other particulates (dust)

18.1 Overview

Summary of the health effects presented by the risk

Workers across the resources industry can be exposed to various dusts and particulates, and consequently there are health impacts depending on the level of exposure that workers experience.
 	
Diseases caused by over-exposure to dust and particulates include:
 	
► Coal Workers' Pneumonoconiosis including Progressive Massive Fibrosis
► Silicosis
► Mixed Dust Pneumoconiosis
► Chronic Obstructive Pulmonary Disease
    ► Chronic bronchitis
    ► Emphysema
    ► Occupational asthma

What we know about the risk (available data and evidence from RSHQ and other sources)
► Regular monitoring of respirable dust levels occurs for many populations in mining. ► The US and UK have published significant bodies of knowledge on the risks and prevalence of mine dust lung disease. Reported cases in Queensland can be found on the Mine Dust Lung Diseases reporting page [1].
How we can learn more about the impact of this risk in the resources sector in Queensland
► Centralised data collection by RSHQ (with data cleansing) will ensure better data collection and analysis going forward.

18.2 What is the health hazard?

The health hazard for dust, silica and other particulates is the inhalation of dust. The consequences vary depending on the size and type of dust and are discussed in further detail in this section.

Regular monitoring of respirable dust levels occurs for many populations in mining. Historical data was requested for the coal mines back to 2000, however some data could not be provided.

18.3 What are the health effects/consequences of exposure?

There are a number of diseases caused by exposure to dust and particulates including:

- Silicosis—caused by exposure to silica dust
- Coal Workers' Pneumoconiosis—The formation of small lesions on the lungs including coal macules and fibrotic nodules caused by long term exposure to coal dust. Historically also referred to as simple pneumoconiosis
- Progressive Massive Fibrosis—a more severe form of pneumoconiosis often referred to as complicated pneumoconiosis with lesions greater than 1 cm in diameter and commonly found in the upper portions on the lungs
- Mixed Dust Pneumoconiosis—pneumoconiosis showing dust macules or mixed-dust fibrotic nodules with or without silicosis nodules
- Chronic Obstructive Pulmonary Disease—an umbrella term for the chronic inflammatory lung disease that causes obstructed airflow from the lungs including chronic bronchitis, emphysema, and occupational asthma
- Chronic bronchitis—long-term inflammation of the bronchi
- Emphysema—damage to the alveoli in the lungs that causes a shortness of breath
- Occupational asthma—an allergic or immunological response to an irritating toxic substance breathed in on the job including chemical fumes, gases, and dusts

18.4 Who is exposed? And how are they exposed?

There is potential for exposure to dust for a large cross section of workers across the resources industries. This may affect all sectors within RSHQ including Coal Mines, Mineral Mines and Quarries, Explosives, and Petroleum & Gas. Potential exposure is possible at any location where a worker has potential to breathe in dust, locations of some of the greatest potential exposures include:

- Underground coal mines
- Underground metal mines
- Surface coal and metals mines
- Preparation plants or mineral processing plants
- Quarries,
- Laboratories
- Exploration drilling
- Natural gas drilling rigs

The consequences of the exposure may depend on the size of particles that the worker is exposed to. Exposure can occur in any environment where dust is present, and many mining processes generate dust.

The **inhalable** particulate fraction is that fraction of a dust cloud that can be breathed into the nose or mouth. Larger inhaled particles may be filtered out by the nasal hairs and retained by the mucous membranes [2].

The **thoracic** particulate fraction is that fraction that can penetrate the airways of the head and enter the airways of the lung. Particles that make it through may deposit in the tracheobronchial airway region. The body may eliminate these particles through the mechanism of mucociliary clearance or they may be dissolved and enter the body if soluble [2].

The **respirable** particulate fraction is that fraction of inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. This is the size fraction that is of the most concern for mine dust lung diseases and most historical measurements of this respirable fraction. Examples of dusts for which the respirable fraction offers greatest hazard include quartz and other dusts containing free crystalline silica. Particles smaller than this may penetrate to the alveolar region. Only 1% of particles of 10 μm makes it to the alveolar region so this is normally considered the limits for the respirable fraction of dust [2].

The **submicron** particulate fraction are those particles less than 1 μm in diameter. Historically there was not much research on or measurement of the submicron particles. This may be due to the inability to accurately measure the submicron fraction quickly and efficiently in an economic manner. However, recent research has shown that large numbers of submicron particles sexist in mining environments and are most likely making a significant contribution to the health hazard [2].

The **ultrafine** particulate fraction consists of particles which are less than 0.1 μm or 100 nanometres in diameter. Measurement of diesel particulate is commonly in nanometres. Nanoparticles have very little mass and ultrafine measurements of diesel particulate matter are often based on combustion instead of mass [2].

Fibrous dust including asbestos present special health problems related to the shape of the particles. Particles of diameter < 3 μm and length > 5 μm with an aspect ratio greater than 3 to 1 are classified as fibres. Fibres act differently than other particles and fine fibres as long as 100 μm have been found in pulmonary spaces. The aerodynamic diameter of the fibre is primarily a function of its diameter and not its length [2].

18.5 What are the current QLD regulatory requirements for the management of the hazard?

The various sizes and mineralogies of dusts have their own regulatory requirements in the different legislations as listed below. This legislation sets exposure limits for various types of dust, prescribes a sampling methodology and gives guidance on other aspects of sampling.

Respirable dust and silica are managed and controlled in Queensland by the following legislation:

- *Coal Mining Safety and Health Act 1999* [3]
- *Coal Mining Safety and Health Regulation 2017* [4]
- *Mining and Quarrying Safety and Health Act 1999* [5]
- *Mining and Quarrying Safety and Health Regulation 2017* [6]
- *Recognised Standard 14: Monitoring respirable dust in coal mines* [7]
- *Recognised Standard 15: Underground respirable dust control* [8]

- *QGL02: Guideline for management of respirable dust in Queensland mineral mines and quarries* [9]
- *AS 2985: Workplace Atmospheres: Method for sampling and gravimetric determination of respirable dust* [10]

18.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Most countries have a workplace exposure standard for respirable coal mine dust, which vary from country to country. These limits can be seen below in Table 38. There may be a number of factors contributing to the differences in WESs including:

- Risk tolerance of the country
- When the limits were set or revised
- The variations in prevalence rate for particular coal basins

Some jurisdictions set different limits for anthracite coal, reflecting the importance of coal rank on the prevalence rate of mine dust lung disease.

Table 38: Workplace Exposure Standards for Respirable Coal Dust in Various Countries

Country	WES All Coal Dust (mg/m^3)	WES Bituminous and/or lignite (mg/m^3)	WES Anthracite (mg/m^3)
Belgium		0.9	0.4
Canada-Ontario	0.9		
Ireland	1.6	0.9	
Latvia	4.0		
Spain	0.9		
Denmark	2.0		
New Zealand	3.0		
China	2.5		
South Korea	1.0		
USA –OSHA	2.4		
USA –MSHA	1.5		
UK	4.0		
Safe Work Australia (2019) Coal Dust (Containing < 5 % Quartz) (original recommendation)		0.9	0.4
DFG	1.5		
South Africa	2.0		
USA-NIOSH	1.0		
ACGIH	0.9		
Queensland	1.5		
NSW	1.5		

Table 39: Workplace Exposure Standards for Inhalable Coal Dust in Various Countries

Country	WES (mg/m^3)
People's Republic of China	4.0
NSW	10.0

18.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

Mining legislation is state based in Australia, and each state sets its own WESs. Many of the exposure standards have been recently revised.

Table 40: Queensland Exposures Standards

Dust	mg/m^3	As of
Respirable dust–Coal mines	1.5	1 Sept 2020
Respirable dust–Mineral mines and quarries	5.0	
Diesel emissions	0.1*	
Respirable crystalline silica	0.05	1 Sept 2020
Inspirable dust	10.0	

**DPM exposure limits is a recommended guidance value, not a regulatory limit*

Table 41: New South Wales Exposure Standards

Dust	mg/m^3	As of
Respirable dust–Coal mines	1.5	1 Feb 2021
Respirable dust–Mineral mines and quarries	5.0	
Diesel emissions	0.1	1 Feb 2021
Respirable crystalline silica	0.05	1 July 2020
Inhalable dust	10	

Table 42: Western Australia Exposure Standards

Dust	mg/m3	As of
Respirable dust–Coal mines	1.5	27 October 2021
Respirable dust–Mineral mines and quarries	3.0	
Diesel emissions	0.1	
Respirable crystalline silica	0.05	27 October 2020
Inhalable dust	10	

18.8 How is the hazard measured/evaluated in the workplace?

18.8.1 Current method and its limitations

AS 2985 is the gravimetric method for determining dust exposure concentrations. There are currently no other specified methods for personal dust determination in occupational hygiene. This method requires filters to be weighed by an external laboratory and results aren't often obtained for a week or two after the exposure.

Environmental monitoring has a range of methods that should be reviewed for applicability to occupational hygiene exposures. For instance, there is an Australian Standard for the use of TEOMs (tapered element oscillating microbalances) in environmental monitoring, but there is not an equivalent Australian Standard for use in occupational hygiene. TEOMs are used overseas for personal exposure monitoring as they provide accurate near real-time feedback (see next section for more information).

18.8.2 Emerging technology/research

Real-time monitoring technology continues to develop including light-scatter and TEOM devices. Australian mines have already started to implement some of this technology for dust monitoring and control. This can provide immediate feedback to the workers to allow for interventions before personal overexposure occurs. Light scattering technology is best suited to source and peak identification providing instantaneous reading of relative concentrations of dust. TEOM technology provides mass based near real-time feedback to miners and can be used for personal exposure sampling.

As noted below in the literature review, it is not simply the mass of exposure dust that correlates to the incidence of MDLDs. Characterisation of dust is taking place in Australia and the US to determine the mineralogy, shape and particle size distributions of the dust occurring to help determine what influence these factors have on the disease prevalence rates in different mining regions [11-15].

18.9 What health monitoring data is currently available to RSHQ?

18.9.1 What is the status of the data/issues with the data?

Historical data is spotty. Centralised data collection by RSHQ with data cleansing will ensure better data collection going forward.

18.9.1.1 Coal mines

There were 40,567 valid samples included in the data set analysed for respirable coal dust for the coal mines, which are analysed in Appendix C.

There were 49 SEGs represented in the data including surface, underground and processing SEGs. These were grouped by SEG Code with 3,333 samples in QCP (coal processing), 15,081 samples in QCS (surface coal) and 22,153 samples in QCU (underground coal).

The average value of the underground samples as well as the normal parametric 95% Upper confidence limit (UCL) and lognormal parametric 95% UCL (Log UCL) are all above 1.0 mg/m^3. The UCLs are a statistical measure that calculates with 95% confidence the level that the true average exposure will be less than. The normal parametric UCL is for normally distributed data, while the lognormal parametric UCL is more appropriate for lognormally distributed data.

There are many exposure samples for coal mines, especially underground which provides a more robust analysis. The number of samples has increased significantly since 2016.

The average exposure level for underground coal mines has decreased over the years. The average exposure was above 1.5 mg/m^3 before 2015 which indicates that historic exposures were high, and more miners may develop mine dust lung disease in coming years.

Very little data exists for surface coal mines before 2017.

The following conclusions were made based on the data analysis in Appendix C:

- The longwall production and development production SEGs historically have had high exposures which have decreased in recent years. (Appendix C: RCD Exposure for LW Production SEG by Year and RCD Exposure for Development Production SEG by Year)
- Ventilation control device (VCD) installer exposures are still not as well controlled. (Appendix C: RCD Exposure for VCD Installers by Year)
- There are many RCS exposure samples for coal mines over the last three years. Data before 2017 is not included
- The stone drivage SEG shows an average and LOG UCL above half the OEL and a UCL above the exposure limit. Very few stone drivage samples have been taken in 2019 and 2020

This data set was found to have fewer errors and erroneous categorisations than the MMQ data, which is most likely a result of the increased emphasis on education for those collecting the samples and the greater focus of RSHQ on data verification and reporting in coal.

18.9.1.2 Mineral mines and quarries

A total of 7,337 samples were analysed for the Mineral Mines and Quarries data for the 2017 to 2020 period which are analysed in Appendix G. These covered the areas of mineral processing, dredging operations, exploration, surface, surface alluvial gold, surface, or underground gemstone, underground, quarry and quarry-group. Quarry, surface, and underground mine types were the only groups with over 100 samples. Many of the other mine types have very few samples taken, which may not be representative of the sector as a whole.

It is important to recognise the limitations of analysing exposure data from mineral mines and quarries. A large variability in the size and function of operations within the mineral mines and quarries sector make comparative assessments challenging. Additionally, workers tend to rotate between roles within the same operation, meaning SEGs are difficult to apply. This is evidenced through the high Geometric Standard Deviations reported against mine types and SEGs. The complexity of the work environment should be taken into account when reviewing this analysis.

Very few samples are in the data set for quarry-group, surface or underground gemstone, surface alluvial gold, exploration, and dredging operations. This makes it difficult to accurately estimate the exposures for these groups.

Respirable crystalline silica exposure is a more significant issue than total respirable dust exposure based on current exposure samples. However, the number of alumino-silicates and other mineralogical components is not considered in total dust levels.

The mineral processing mine type should be reviewed for the applicability of all SEGs attributed to this mine type. Some clearly appear to be mining activities and not mineral processing.

Several SEGs should be the subject of further investigation:

- Shotcreting—ensure adequate RPE to protect workers performing the task and anyone in the area.
- Cleaners—there were only 4 samples from quarry cleaners, but one was 19.54 mg/m3 and the comments indicated that this is representative of the workers' exposure.

- Respirable crystalline silica exposure is a significant issue for mineral mines and quarries. The average exposures are high for the minerals processing, exploration, and surface alluvial gold mine types. A number of the SEGs in all mine types are not well controlled as evidenced by the amber and red lights in the tables.

18.10 What does it tell us about workers' exposures?

Generally, worker exposures to both dust and RCS have been reduced with the focus on dust since 2015. While the exposure standards have decreased, the long latency of disease means we may continue to see mine dust lung diseases being diagnosed for some time. As of 31 July 2021 there have been 225 cases of MDLDs reported to RSHQ including 134 pneumoconiosis cases [1].

These initiatives are also aided by the reforms made to the Health Surveillance system in Queensland in recent years for the better detection of disease. Disease reporting to the RSHQ is also now mandatory.

A register of approved health practitioners was set up including doctors, and providers of X-ray images and spirometry, with a new set of standards in training qualifications and experience. This included the introduction of new standards for chest X-ray imaging and spirometry in accordance with ILO guidelines. Chest X-rays are now dual read by qualified B-readers.

18.11 How could data collection and management be improved?

Centralised collection of dust data—that includes data review and cleansing for all inspectorates, as applicable—is the first step.

A review should be undertaken of the MMQ SEGs. Some SEG groups have high variability as evidenced by the high geometric standard deviations (GSDs) calculated, which has previously been identified by RSHQ. The exposures for SEGs with high GSDs should be reviewed and split into subgroups where necessary. This will allow for similar exposures to be properly grouped together and provide insights into higher risk activities and inform prioritisation of control measures.

Also, in the MMQ group, some mine types have large numbers of samples in "N/A" or "not otherwise classified" SEG categories, Many of the N/A or NOC classifications clearly belong in another SEG group based on primary activity listed, which indicates that the current SEG groups are not being used correctly. In addition to the overall SEG structure being reviewed, the data received by RSHQ should be reviewed for appropriate categorisation.

18.12 What other exposure data is available/in peer reviewed literature?

18.12.1 Respirable coal dust

Occupational diseases, including mine dust lung disease, have been recognised in mining for centuries. A more detailed review of the history of the respirable coal dust and silica exposure standards and their impact on the setting of Australian standards has recently been published which is summarised here [16].

The setting of a workplace exposure standard for coal dust began in the United Kingdom. The Pneumoconiosis Research Unit (PRU) was established in 1945 and by 1952 researchers had determined that coal workers' pneumoconiosis could be divided into simple pneumoconiosis and complicated pneumoconiosis (or Progressive Massive Fibrosis (PMF)).

The Pneumoconiosis Field Research Unit Interim Standards Study (ISS) was established in 1952 due to lingering uncertainties of the true prevalence of pneumoconiosis throughout the UK as well as the attack and progression rates of the disease under various conditions. In this study, the National Coal Board (NCB) aimed to find a "safe" exposure standard in terms of dust quantity and quality plus the relationship between the disease and respiratory disability, further analysis was also conducted in later years [17-23]. It was clear that the disease prevalence rates at some collieries is far higher or lower than the average values at a given exposure level [24-26]. This tells us that the total amount of dust exposure is not the only factor associated with disease prevalence, and that other factors, such as the properties of the region or coal seam, must also be playing a role.

The dust alone was considered to be the cause of simple pneumoconiosis while complicated pneumoconiosis was thought to be caused by the addition of an infection, probably tuberculous onto lungs already affected by coal dust. PMF was initially thought to be very unlikely to develop from cases below Category 2 CWP [27-29]. However, it was later identified that contrary to Cochrane's findings, PMF could develop from Category 0 or 1 CWP [30-34].

The United States Mine Safety and Health Administration (MSHA) reduced the coal dust exposure limit from 3.0 to 2.0 mg/m^3 in 1972. And then again from 2.0 mg/m^3 to 1.5 mg/m^3 on 1 August 2016. The 1972 change in the standard, was based on the UK data from the Pneumoconiosis Field Research study. Attfield (1992) commented on the validity of extrapolating the results from previous studies of British mines to the US situation stating it may not be possible "given that such an evaluation would require knowledge that is now unavailable (such as that particle-size distributions or composition for mines that are now closed)" [35]. He also noted that the British studies were based on x-ray readings from international classification standards for pneumoconiosis that were no longer current [35]. Since then a large body of research has been published on the prevalence rates of CWP in the US historically [36-39] and with the more recent resurgence [40-43].

Research has been conducted into exposures and disease prevalence rates for respirable [11, 44, 45] and inhalable coal mine dust [46] in Australia. Other studies have also taken place in other coal mining countries such as Germany [47].

18.12.2 Respirable crystalline silica

The exposure limit for silica is independent of the limit for respirable dust and much of the literature used to set the ACGIH TLV-TWA is for non-coal mining applications [48]. The ACGIH recommends a WES of 0.025 mg/m^3 to protect against silicosis and lung cancer.

There were no studies referenced confirming a protective effect at 0.025, rather studies were cited indicating that 0.05 mg/m^3 "would probably *not* be sufficiently protective of workers' health" [48]. This recommendation comes from the findings of several epidemiological studies that a WES of 0.05 mg/m^3 has not shown a change in longevity or lung function even though a percentage were found to have 1/0 or 1/1 ILO profusion rating [48]. The risk of silicosis and lung cancer were found to significantly increase at levels greater than 0.06 and 0.65 mg/m^3 [49, 50]. There is also evidence that Silicosis can progress even after miners leave the industry and the exposure to silica dust has ceased [51].

In 2019 SafeWork Australia published a report recommending a WES of 0.02 mg/m3 for prevention of fibrosis and silicosis and the minimisation of lung cancer [52]. This report was based on a review of data available from the ACGIH, Deutsche Forschungsgemeinschaft (DFG) (German Research Foundation) and Scientific Committee on Occupational Exposure Limits (SCOEL) set up by the European Commission. After this report was released many of the Australian states, including Queensland, New South Wales and Western Australia dropped their WESs to 0.05 mg/m^3.

For the UK data, in the Hurley et al., (1982) study, silica did not explain the variation in predicted incidence of CWP by colliery. However, there was evidence that some miners show unusual radiological changes when exposed to coal mine dust with a relatively high quartz content [24].

Hurley hypothesised that a slight overall quartz effect may remain hidden as a miners estimated lifetime exposure to quartz is less accurate than his corresponding mixed dust exposure estimate [24].

Exposures to respirable crystalline silica in coal mines and quarries have also been documented in Australia [53, 54]. The Coal Services Review of the Health Effects associated with Exposures to Respirable Crystalline Silica in Coal Dust recommended the adoption of the proposed TWA of 0.1 mg/m^3 for silica in AS2985-2004, from the current standard of 0.15 mg/m^3 [54]. Hedges et al 2009 found that two of the five quarries that they monitored had an average exposures above the shift adjusted OEL [53].

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Volatile organic compounds

19. Volatile organic compounds

19.1 Overview

Summary of the health effects presented by the risk
► Some Volatile Organic Compounds (VOCs) chemicals are carcinogenic ► Most cause acute irritation to the eyes, respiratory tract, and occupational asthma
What we know about the risk (available data and evidence from RSHQ and other sources)
► Exposure data could not be provided by RSHQ to evaluate the level of risk ► The granularity of the Workers' Compensation data did not permit identification of any VOC-related diseases ► Companies using VOCs are required to manage them in accordance with hazardous chemical regulation and Recognised Standard 16 for underground coal mines
How we can learn more about the impact of this risk in the resources sector in Queensland?
► It is recommended that targeted assessments of individual mine usage of particular VOCs be undertaken to ensure compliance with regulation ► A program such as Health Watch (Monash University 2018), could be implemented, where there is significant potential for VOCs to cause harm ► It has become evident that a major potential path of contamination is through the skin rather than breathing in an aerosol

A volatile organic compound (VOC) is any chemical compound based on carbon with a vapour pressure of at least 0.01kPa at 250°C or having a corresponding volatility under the particular conditions of use. There are over 2500 organic compounds classified as VOCs. Most are used as solvents for cleaning or degreasing agents, paint strippers etc, some may be present in crude oil such as the petroleum distillates, others may be present in coal seam gas (saturated hydrocarbons). Some may be used as reagents in the processing of ores. Petrol and Diesel fuel are mixtures of VOCs.

Some of the more common VOC groups are:

► Aldehydes such as Acetaldehyde or formaldehyde (see chapter 17 - Polymeric Chemicals)
► Acids such as Acetic acid
► Ketones such as Acetone
► Alcohols such as Allyl alcohol, Ethyl alcohol, Methanol
► Aromatic Hydrocarbons such as Benzene, Naphthalene, Toluene
► Aromatic Alcohols such as Phenol (see chapter 17 - Polymeric Chemicals)
► Cyclic non-aromatic hydrocarbons such as Cyclohexane
► Acetates such as Ethyl acetate

- Saturated Hydrocarbons such as Hexane, Octane, Propane
- Polycyclic Aromatic Hydrocarbons (PAHs) such as Benz(a)pyrene
- Polychlorinated Biphenyls (PCBs)—used to be used in transformers as cooling fluids
- Petroleum distillate containing many different saturated and unsaturated hydrocarbons
- Mineral oils—higher order petroleum distillate consisting mainly of saturated hydrocarbons
- Vegetable oils—mixtures of triglycerides
- Nitrogen containing aromatic hydrocarbons such as Pyridine
- Chlorinated hydrocarbons such as Trichloroethylene, methylene chloride

19.2 What is the health hazard?

By their nature, these compounds can pose a threat through inhalation, ingestion, and absorption through the skin and other exposed surfaces.

19.3 What are the health effects/consequences of exposure?

A detailed description of the potential health effects can be found in the ILO guide to Encyclopedia Chapter 104— Guide to Chemicals. This document highlights that in many cases the primary pathway that causes harm is absorption through the skin, not breathing in an aerosol.

Table 43: Common VOCs and associated health hazards

Chemical group	Health hazard
Aldehydes such as Acetaldehyde or formaldehyde (see Polymeric chemicals)	Respiratory irritant and of the eyes. Narcotic of nervous system High concentrations cause headache stupor bronchitis, kidney, liver and heart damage and pulmonary oedema. Acetaldehyde is classified as a Class 2B carcinogen.
Acids such as Acetic acid	Skin irritant, attacks respiratory and digestive tract, chronic exposure can cause bronchitis and palpebral oedema.
Ketones such as Acetone	*Acetone* may be absorbed into the blood through the lungs and diffused throughout the body. Small quantities may be absorbed through the skin. Typical symptoms following high levels of acetone exposure include narcosis, slight skin irritation and more pronounced mucous membrane irritation. Exposure to high concentrations produces a feeling of unrest, followed by progressive collapse accompanied by stupor and periodic breathing, and, finally, coma. Nausea and vomiting may also occur and are sometimes followed by bloody vomiting. In some cases, albumin and red and white blood cells in the urine indicate the possibility of kidney damage, and in others, liver damage can be presumed from the high levels of urobilin, and the early appearance of bilirubin reported. The longer the exposure, the lower the respiratory rate and pulse; these changes are roughly proportionate to the acetone concentration. Cases of chronic poisoning resulting from prolonged exposure to low concentrations of acetone are rare; however, in cases of repeated exposure to low concentrations, complaints were received of headache, drowsiness, vertigo, irritation of the throat, and coughing
Alcohols such as Allyl alcohol, Ethyl alcohol, Methanol	Inhalation and ingestion causing headaches, vertigo, insomnia, affecting vision and in extreme cases blindness

Chemical group	Health hazard
Aromatic Hydrocarbons such as Benzene, Xylene, Naphthalene, Toluene	*Acute and chronic health hazards*. Toluene has an acute toxicity somewhat more intense than that of benzene. At a concentration of about 200 or 240 ppm, it gives rise after 3 to 7 h to vertigo, dizziness, difficulty in maintaining equilibrium, and headache. Stronger concentrations may result in a narcotic coma. The symptoms of chronic toxicity are those habitually encountered with exposure to the commonly used solvents, and include irritation of the mucous membrane, euphoria, headaches, vertigo, nausea, loss of appetite, and alcohol intolerance. These symptoms generally appear at the end of the day, are more severe at the end of the week, and become less or disappear during the weekend or on holiday *Naphthalene* is readily flammable and, in particulate or vapour form, will form explosive mixtures with air. Its toxic action has been observed primarily as a result of gastrointestinal poisonings in children who mistook mothballs for sweets and is manifested by acute haemolytic anaemia with hepatic and renal lesions and vesical congestion. There have been reports of serious intoxication in workers who had inhaled concentrated naphthalene vapours; the most common symptoms were haemolytic anaemia with Heinz bodies, hepatic and renal disorders, and optic neuritis. Prolonged absorption of naphthalene may also give rise to small punctiform opacities in the periphery of the crystalline lens, with no functional impairment. Eye contact with concentrated vapours and condensed micro-crystals may result in punctiform keratitis and even chorioretinitis. Skin contact has been found to cause erythemato-exudative dermatitis; however, such cases have been attributed to contact with crude naphthalene which still contained phenol, which was the causative agent of the foot dermatitis encountered amongst workers who discharge naphthalene crystallization trays
Aromatic Alcohols such as Phenol (see Polymeric chemicals)	Phenol is readily absorbed through the skin and from the gastroenteric tract, while phenol vapours are readily absorbed into the pulmonary circulation. After absorption of a sublethal dose, most of the phenol is oxidized or conjugated with sulphuric, glucuronic, and other acids, and excreted with the urine as "conjugated" phenol. A small portion is excreted as "free" phenol. The toxic effects of phenol are related directly to the concentration of free phenol in the blood. In humans, acute phenol poisoning results in vasodilation, cardiac depression, hypothermia, coma, and respiratory arrest. Ingested phenol causes intense abdominal pain, and mouth burning occurs. Acute renal failure may also result. In animals, the signs of an acute intoxication are very similar, regardless of the site or the mode of administration of this compound. The predominant effects are exerted upon the motor centres in the spinal cord, resulting in tremors and severe convulsions. Chronic phenol poisoning is reported comparatively infrequently today. Severe cases are characterized by systemic disorders such as digestive disturbances, including vomiting, difficulty in swallowing, ptyalism, diarrhoea and anorexia; by nervous disorders, with headache, fainting, vertigo, and mental disturbances; and possibly by ochronosis and an eruption on the skin. The prognosis is grave when there is extensive damage to the liver and kidneys. Ingestion of a dose of 1g of phenol has been lethal to humans. Approximately every second reported case of acute phenol poisoning has resulted in death.
Cyclic non-aromatic hydrocarbons such as Cyclohexane	They may produce toxic effects by inhalation and ingestion, and they have an irritant and defatting action on the skin. In general, the cycloparaffins are anaesthetics and central nervous system depressants, but their acute toxicity is low and, due to their almost complete elimination from the body, the danger of chronic poisoning is relatively slight

Chemical group	Health hazard
Acetates such as Ethyl acetate	Ethyl acetate is an irritant of the conjunctive and mucous membrane of the respiratory tract. Animal experiments have shown that, at very high concentrations, the ester has narcotic and lethal effects; at concentrations of 20,000 to 43,000 ppm, there may be pulmonary oedema with haemorrhages, symptoms of central nervous system depression, secondary anaemia, and damage of the liver. Lower concentrations in humans have caused irritation of the nose and pharynx; cases have also been known of irritation of the conjunctiva with temporary opacity of the cornea. In rare cases, exposure may cause sensitization of the mucous membrane and eruptions of the skin.
Saturated Hydrocarbons such as Hexane, Octane, Propane	Pharmacologically, the hydrocarbons above ethane can be grouped with the general anaesthetics in the large class known as the central nervous system depressants. The vapours of these hydrocarbons are mildly irritating to mucous membranes. The irritation potency increases from pentane to octane. In general, alkane toxicity tends to increase as the carbon number of alkanes increases. In addition, straight-chain alkanes are more toxic than the branched isomers. The liquid paraffin hydrocarbons are fat solvents and primary skin irritants. Repeated or prolonged skin contact will dry and defat the skin, resulting in irritation and dermatitis. Direct contact of liquid hydrocarbons with lung tissue (aspiration) will result in chemical pneumonitis, pulmonary oedema, and haemorrhage. Chronic intoxication by n-hexane or mixtures containing *n*-hexane may involve polyneuropathy.
Polycyclic Aromatic Hydrocarbons (PAHs) such as Benz(a)pyrene	benzo(a) and dibenzo derivatives of pyrene are very potent carcinogens
Polychlorinated Biphenyls (PCBs)—used to be used in transformers as cooling fluids	In people occupationally exposed to PCBs, a broad spectrum of adverse health effects has been reported. Effects include skin and mucous membrane changes, swelling of the eyelids, burning of the eye, and excessive eye discharge. Burning sensation and oedema of the face and hands, simple erythematous eruptions with pruritus, acute eczematous contact dermatitis (vesiculo-erythematous eruptions), chloracne (an extremely refractory form of acne), hyperpigmentation of skin and mucous membranes (palpebral conjunctiva, gingiva), discolouration of fingernails and thickening of the skin can also occur. Irritation of the upper respiratory airways is frequently seen. A decrease in forced vital capacity, without radiological changes, was reported in a relatively high percentage of the workers exposed in a capacitor factory. Digestive symptoms such as abdominal pain, anorexia, nausea, vomiting and jaundice, with rare cases of coma and death, may occur. At autopsy, acute yellow atrophy of the liver was found in lethal cases. Sporadic cases of acute yellow atrophy of the liver were reported. Neurological symptoms such as headache, dizziness, depression, nervousness, and so on, and other symptoms such as fatigue, loss of weight, loss of libido and muscle and joint pains were found in various percentages of exposed people. PCBs are Group 2A carcinogens (probably carcinogenic to humans) according to the IARC evaluation. After the environmental disaster in Yusho, Japan, where PCBs contaminated cooking oils, an excess of malignant tumours was observed. Pathological pregnancies (toxaemia of pregnancy, abortions, stillbirths, underweight births and so on) were frequently associated with increased PCB serum levels in Yusho patients and in the general population.
Petroleum distillate containing many different saturated and unsaturated hydrocarbons	See saturated hydrocarbons

Chemical group	Health hazard
Mineral oils—higher order petroleum distillate consisting mainly of saturated hydrocarbons	See saturated hydrocarbons
Vegetable oils—mixtures of triglycerides	irritation eyes, skin, respiratory system; lacrimation (discharge of tears)
Nitrogen containing aromatic hydrocarbons such as Pyridine	*Pyridine and homologues.* Some information on pyridine is available from clinical reports of human exposure, primarily through medical treatments or through exposure to the vapour. Pyridine is absorbed through the gastrointestinal tract, through the skin and by inhalation. Clinical symptoms and signs of intoxication include gastrointestinal disturbance with diarrhoea, abdominal pain and nausea, weakness, headache, insomnia, and nervousness. Exposures less than those required to produce overt clinical signs may cause varying degrees of liver damage with central lobular fatty degeneration, congestion, and cellular infiltration; repeated low-level exposures cause cirrhosis. The kidney appears to be less sensitive to pyridine-induced damage than is the liver. In general, pyridine and its derivatives cause local irritation on contact with the skin, mucous membranes, and cornea. The effects on the liver may occur at levels that are too low to elicit a response from the nervous system, and so no warning signs may be available to a potentially exposed worker. Further, although the odour of pyridine is easily detectable at vapour concentrations of less than 1 ppm, odour detection cannot be relied upon because olfactory fatigue occurs quickly.
Chlorinated hydrocarbons such as Trichloroethylene, methylene chloride	Methylene chloride has been classified by IARC as a possible human carcinogen The principal acute toxic action of dichloromethane is exerted on the central nervous system—a narcotic or, in high concentrations, an anaesthetic effect; this latter effect has been described as ranging from severe fatigue to light-headedness, drowsiness and even unconsciousness. The margin of safety between these severe effects and those of a less serious character is narrow. The narcotic effects cause loss of appetite, headache, giddiness, irritability, stupor, numbness and tingling of the limbs. Prolonged exposure to the lower narcotic concentrations may produce—after a latent period of several hours—shortness of breath, a dry, non-productive cough with substantial pain and possibly pulmonary oedema. However, mild intoxication does not seem to produce any permanent disability, and the potential toxicity of dichloromethane to the liver is much less than that of other halogenated hydrocarbons (in particular, carbon tetrachloride). Irritation of the skin and eyes may be caused by direct contact, yet the chief industrial health problems resulting from excessive exposure are the symptoms of drunkenness and incoordination that result from dichloromethane intoxication and the unsafe acts and consequent accidents to which these symptoms may lead. Dichloromethane is absorbed through the placenta and can be found in the embryonic tissues following exposure of the mother; it is also excreted via milk. Inadequate data on reproductive toxicity are available to date Trichloroethylene has primarily a narcotic effect. In exposure to high concentrations of vapour (above about 1,500 mg/m^3) there may be an excitatory or euphoric stage followed by dizziness, confusion, drowsiness, nausea, vomiting and possibly loss of consciousness. In accidental ingestion of trichloroethylene, a burning sensation in the throat and gullet precedes these symptoms. In inhalation poisonings, most manifestations clear with the breathing of uncontaminated air and elimination of the solvent and its metabolites. Nevertheless, deaths have occurred as a result of occupational accidents.

Chemical group	Health hazard
	Prolonged contact of unconscious patients with liquid trichloroethylene may cause blistering of the skin. Another complication in poisoning may be chemical pneumonitis and liver or kidney damage. Trichloroethylene splashed in the eye produces irritation (burning, tearing and other symptoms). After repeated contact with liquid trichloroethylene, severe dermatitis may develop (drying, reddening, roughening, and fissuring of the skin), followed by secondary infection and sensitization. Trichloroethylene is classified as a Group 2A probable human carcinogen by IARC. In addition, the central nervous system is the main target organ for chronic toxicity. Two types of effects are to be distinguished: ► Narcotic effect of trichloroethylene and its metabolite trichloro ethanol when still present in the body ► The long-lasting sequalae of repeated over-exposures. The latter may persist for several weeks or even months after the end of the exposure to trichloroethylene The main symptoms are lassitude, giddiness, irritability, headache, digestive disturbances, intolerance of alcohol (drunkenness after consumption of small quantities of alcohol, skin blotches due to vasodilation—" degreaser's flush"), mental confusion. The symptoms may be accompanied by dispersed minor neurological signs (mainly of brain and autonomic nervous system, rarely of peripheral nerves) as well as by psychological deterioration. Irregularities of cardiac rhythm and minor liver involvement have rarely been observed.

19.4 Who is exposed? And how are they exposed?

- Generally, it will be maintenance/service personnel who are most at risk due to their use of solvents, greases, degreasers, and paints
- Petroleum workers may be exposed to various hydrocarbon compounds from crude oil
- Some chemicals may be used in the processing of ores

19.5 What are the current QLD regulatory requirements for the management of the hazard?

Queensland regulations do not specifically cover VOCs, however if designated a hazardous chemical (as defined in either the CMSHR 2017 or MQSHR 2017) it should be managed accordingly.

A hazardous chemical is a substance, mixture or article that satisfies the criteria for a hazard class in the Globally Harmonised System (GHS) (including a classification mentioned in schedule 2AAA), but does not include a substance, mixture or article that satisfies the criteria solely for 1 of the following hazard classes:

- Acute toxicity—oral—category 5
- Acute toxicity—dermal—category 5
- Acute toxicity—inhalation—category 5
- Skin corrosion/irritation—category 3
- Serious eye damage/eye irritation—category 2B

- Aspiration hazard—category 2
- Flammable gas—category 2
- Acute hazard to the aquatic environment—category 1, 2 or 3
- Chronic hazard to the aquatic environment—category 1, 2, 3 or 4
- Hazardous to the ozone layer

Part 7 of the CMSHR 2017 and the MQSHR 2017 describes Hazardous Chemicals and dangerous goods. The subdivisions and sections describe:

- The meaning of hazardous chemical and dangerous goods
- The need for the Site Senior Executive (SSE) to maintain a register of hazardous chemicals and dangerous goods
- The requirements for manufacturers, suppliers, and importers to mark and label substances
- The need for the SSE to ensure that hazardous chemicals and dangerous goods are correctly marked and labelled
- The SSE must ensure that a hazardous chemical or dangerous good selected for use at the mine does not create an unacceptable level of risk to a person when used, handled, or stored under standard work instructions
- The SSE must ensure that the mine has standard work instructions (SWI) for using, handling, or storing hazardous chemicals or dangerous goods
- The risk at a mine relating to the handling or storing of a hazardous chemical or dangerous goods must be managed
- The SSE must ensure that appropriate monitoring in relation to a hazardous chemical or dangerous goods is carried out as part of any SWI or other procedure that applies to monitoring
- The SSE must ensure that the mine has a SWI for dealing with leaks and spills
- The SSE must ensure that the mine disposes of hazardous chemicals or dangerous goods appropriately

Exposure to hazardous chemicals that causes or has the potential to cause a significant adverse effect on the safety or health of a person is classified as a high potential incident under CMSHR 2017 Schedule 1C and MQSHR 2017 Schedule 1. No HPI have been reported in the data supplied by RSHQ relating to these chemicals.

Division 3 and subsidiary sections of the MQSHR 2017 outline the requirements for health surveillance for the non-coal mining sector. Health surveillance is required if the SSE reasonably believes or ought to reasonably believe that exposure to a hazard at the mine may cause or result in an adverse health effect under the worker's work conditions and either there exists a valid technique capable of detecting signs of the health effect, or a valid biological monitoring procedure is available to detect the changes from the current accepted values for the hazard. S139 describes the requirements to remove any affected worker from the work environment. S140 describes the use of PPE to manage the exposure if a mine cannot prevent or reduce the exposure by other means.

Subdivision 3 of Division 2 of the CMSHR 2017 describes the requirements for the Coal Mine Workers Health Scheme which includes similar requirements to the above. S49 specifically requires that the mines Safety and Health Management System must provide for periodic monitoring of the level of risk from hazards at the mine from hazards that are likely to create an unacceptable level of risk. It also requires the employer to ensure that the workers exposure to the hazard is periodically monitored to assess the level of risk to the worker if the worker is exposed to a hazard at a coal mine that may increase the level of risk. CMSHR -1 Health assessment form lists under question 1.5: Specific coal mine worker position requirements or hazard exposures, section (c) – 'Coal mine worker may potentially be exposed to a list of specific hazardous chemicals including:'

- Oils, greases
- Solvents
- Phenols
- Isocyanates
- Acids
- Alkalis
- Cement, grout, stone dust
- Detergent, hand cleaners

The medical examination includes assessment of the skin.

Schedule 1C lists a number of notifiable diseases mainly relating to respiratory issues, but also including cancers (Schedule 1 in the CMSHR 2017). Schedule 5 refers to general exposure limits for hazards deferring to the National Occupational Health and Safety Commission (NOHSC, 1985-2005) document—Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995). Note this document has been superseded by the Safe Work Australia Workplace Exposure Standards for Airborne Contaminants, last issued 2019 (presently undergoing review).

Recognised Standard 17, 'Recognised Standard for Hazardous Chemicals' under the CMSHA (1999) is a comprehensive document aimed at assisting coal mines in managing the risks associated with hazardous chemicals. Its contents include:

- Classification and labelling of workplace hazardous chemicals
- Manifests and placarding of hazardous chemicals and dangerous goods
- Preparation of safety data sheets (SDS) for hazardous chemicals

- The content of the SDS including
  - Hazard identification
  - Composition and information on ingredients
  - First aid measures
  - Firefighting measures
  - Accidental release measures
  - Handling and storage
  - Exposure controls and personal protection
    - Exposure control measures
    - Biological monitoring
    - PPE
  - Physical and chemical properties
  - Stability and reactivity
  - Toxicological information
  - Ecological information
  - Disposal considerations
  - Transport information
  - Regulatory information

QGL03 – Guideline for Hazardous Chemicals (July 2019) issued by the then Department of Natural Resources, Mines and Energy outlines the processes for safe acquisition, storage and use of hazardous chemicals in general under the MQSHA 1999. This mirrors RS-19. The controls required depend upon the specifications outlined in the safety data sheets (SDS) supplied for the hazardous chemical. It is therefore vital that the SDS are accurate and comprehensive enough to permit effective management of the risk. Chapter 11 of the guideline outlines these requirements. It lists more than 120 groups of substances or families, that should be used to ensure consistent labelling of hazardous chemicals.

Exposure to hazardous chemicals not on mine sites is managed under the Work Health and Safety Regulation 2011 for non-mine sites. Schedule 14 of this regulation outlines the requirements for health monitoring (Division 6, sections 368 to 378) for a range of chemicals

Health monitoring requirements may include:

- Demographic, medical and work history
- Records of personal exposure

- Physical examination with emphasis on areas where chemical has impact e.g. respiratory system, peripheral nervous system, or skin
- Urinary/blood analysis

Form 28, 'Hazardous chemical health report', outlines the reporting requirements for any person being assessed for potential adverse health effects due to hazardous chemicals. This form must be sent to WHSQ.

In 2013 WHSQ issued a code of practice for managing the risks associated with hazardous chemicals in the workplace. This document aligns with the Safe Work Australia Code of Practice described below (WHSQ, 2013).

19.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

Safe Work Australia have issued a Code of Practice for managing the risks of hazardous chemicals (Safe Work Australia, 2020). This is a more comprehensive document than RS-19 and QGL-03, in that it details the overall risk management process (identification, assessment, control identification, monitoring and review, emergency preparedness), as well as the technical components that make up the management process. Each section is referenced back the to the relevant model WHS regulation. More details on the management of hazardous chemicals can be found on the Safe Work website: https://www.safeworkaustralia.gov.au/chemicals, including guidance on health monitoring.

The health monitoring requirements echo those in the CMSHR 2017 and MQSHR 2017. It includes a list under the Model WHS Regulations of restricted use chemicals—in particular, benzene, methanol, tetrachloroethane, tetrachloromethane and PCB's. Appendix J outlines the requirements for health monitoring under the model WHSR for specific chemicals, including those where biological monitoring is recommended.

The NSW Workplace Safety and Health (Mines and Petroleum Sites) Regulation 14 requires the development and implementation of an Airborne Contaminants Principal Hazard Management Plan (PHMP) for any chemical or biological contaminant likely to be in the air which include hazardous chemicals. Section 1.3.4 details the requirements for Health Monitoring. Xanthates are listed among the list of common airborne contaminants. It provides a table which identifies potential airborne contaminants associated with specific mining and mineral processing activities.

The NSW Resource Regulator published a guide on how to prepare the PHMP and its required elements (RR, 2018). To assist the development of the PHMP the Resource Regulator has published an information document describing atmospheric contaminants that may exist at worksites, the possible health effects and assistance in risk ranking the hazards. All chemicals used, handled, or stored in a workplace in excess of set allowances under schedule 11 of the NSW WHSR (2017) are notifiable to the Resource Regulator. Schedule 14 of the WSHR (2017) outlines the requirements for health monitoring for specific chemicals, in particular benzene, creosote, and polycyclic aromatic hydrocarbons (PAHs).

In WA, Hazardous substance control is outlined in division 3 of part 7 of the Mine Safety and Inspection Regulation (MSIR, 1995). A "suitable" assessment should be carried out for each hazardous substance: if a significant risk of exposure is identified then a report must be prepared outlining how the risk will be controlled, and this may include exposure monitoring and personal health-surveillance monitoring. DMIRS provide templates for risk assessment, hazardous substance register, a hazardous substance compliance tool including a checklist and hazardous substance training record. DMIRS have issued a Guideline for Risk-based health surveillance and biological monitoring including various forms for notification of outcome of health assessment, biological monitoring result, and notification of occupational disease (DOCEP, 2008).

19.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

The workplace exposure standards have been provided as a table in an appendix of this report. Refer to Appendix J—VOCs Workplace Exposure Standards for details.

19.8 How is the hazard measured/evaluated in the workplace?

19.8.1 Current method and its limitations

There are a wide variety of methods used depending on the type of VOC. Almost all require collection of samples in the field and subsequent processing in the laboratory. This means that there is considerable delay between collecting the sample and reporting the results. This delay hampers the capacity to limit excessive exposure of the worker. Because of the specialised nature of the sampling and the cost of analysis this can also limit the number and frequency of samples taken.

There are two Australian Standard methods:

- *AS2986.1-2003 (R201)—Workplace air quality sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography—pumped sampling method*
- *AS2986.2-2003 (r2016)—Workplace air quality sampling and analysis of volatile organic compounds by solvent desorption/gas chromatography—diffusive sampling method*

OSHA offer methods including:

- Method 32—Phenol and Cresol using analytes are collected on an XAD-7 sampling tube and desorbed with methanol. The analysis is performed by HPLC with ultraviolet (UV) detection at 218 nm
- Method 1007—Formaldehyde—Diffusive samples are collected by exposing either Assay Technology ChemDisk Aldehyde Monitor 571 (ChemDisk-AL), SKC UMEx 100 Passive Sampler (UMEx 100), or Supelco DSD-DNPH Diffusive Sampling Device (DSD-DNPH) to workplace air. Samples are extracted with acetonitrile and analysed by LC using a UV detector
- Method 52—Formaldehyde—using a XAD-7 packed column for absorption and analysis as above

In the NIOSH manual of analytical methods 5th edition Centres for Disease Control and Prevention (NIOSH, 2021) there are a number of methods listed including:

2549 VOCs screening

3900 VOCx C1-C10

2027 Ketones

3800 Acetone, Benzene, Formaldehyde

8319 Acetone and Methyl ethyl ketone in urine

2027 Ketones

2016 Formaldehyde

8007 toluene in blood

8321 o-cresol in urine

8322 trichloroethylene - trichloracetic acid in urine

7907 volatile acids

ASTM (ASTM 1996) list STP1261: Volatile organic compounds in the environment- Systematic single ion chromatograms.

US EPA (USEPA, 1999) methods include:

- 8010A, 8020A, 8021A halogenated and aromatic volatile organic compounds by gas chromatography
- TO15 Hydrocarbons in Air
- TO17 VOCs

19.8.2 Emerging technology/research

In an attempt to overcome the problems outlined above, a number of techniques have been developed. They are not recognised as standard methods but can be used for screening purposes.

- An alternative to the above methods is the use of passive chemical badges. The badge must be attached within the breathing zone of the individual. Badges are available for volatile components such as phenol and formaldehyde. The samples are processed as above. See for example: https://sensorssafety.com/products/formaldehyde-passive-monitoring-badge-4180.
- There are real-time monitors for formaldehyde using electrochemical (EC) sensors e.g., the Formaldemeter (https://www.ppm-technology.com/formaldemeter htv.htm. It takes 10 mL snatch samples by pump. Typically samples every 2 minutes and responds within a minute. The default range is 0-10 ppmv with a resolution of 0.01 ppmv. Accuracy +/- 10 % at 2 ppm. Other ranges can be selected.
- Schettgen et al (2015) developed a simple and sensitive method for determining urinary phenol, involving enzymatic hydrolysis followed by gas chromatography-mass spectroscopy (GC-MS).
- Pala et al (2008) Carried out monitoring of research workers looking at markers in blood, correlation was found between exposure to formaldehyde and formaldehyde human serum albumin conjugate (FA-HSA). Biomarkers of effect did not find evidence of the presence of genetic damage.

19.9 What health monitoring data is currently available to RSHQ?

19.9.1 What is the status of the data/issues with the data?

- No health monitoring data relating to exposure to VOCs could be provided by RSHQ. The Workers' Compensation data did not provide enough detail to identify the causes of many diseases. However, there were a number of cases of contact dermatitis (15), other diseases of the skin (9), asthma (2), bronchitis (36), other respiratory diseases (12) as well as unspecified diseases (5) that may be linked to exposure to VOCs.
- There was one instance of a non-work-related chemical High Potential Incident (form 1A) but this does not appear to be related to VOC exposure.
- The HPI database (2011-2020) only identified instances where the VOC was involved in a fire.
- The LTI database (2011-2020) identified one instance where acetic acid spilled and caused an itch to an eye.

19.9.2 What does it tell us about workers exposures?

This information does not provide any real insight into the potential exposure of workers to VOCs.

19.9.3 How could data collection and management be improved?

Targeted assessment programs looking at the management of hazardous chemicals at selected worksites could investigate what information workplaces have on the risk of exposure to VOCs. Consideration should be given to increased biological monitoring. Exposure monitoring is expensive and not necessarily effective in managing health hazards.

The ILO encyclopedia chapter quoted in section 19.3 above lists examples of biological monitoring that can be included in routine health surveillance monitoring as outlined in the table below.

Table 44: Biological monitoring methods for common VOCs

Chemical	Urine/blood
Carbon Disulphide	Urine
N,N Dimethylformamide	Urine
2-Ethoxy ethanol and acetate	Urine
Hexane	Both
Methanol	Urine
Styrene	Both
Toluene	Both
Trichloroethylene	Both
Xylenes	Both

A program such as Health Watch (Monash University 2018), could be implemented, where there is significant potential for VOCs to cause harm. Health Watch is an epidemiological health surveillance program established by the Australian Institute of Petroleum primarily aimed at relating the causes of cancer and death in the industry. Since 2005 the study has been executed by researchers from Monash University. Health Watch covers those petroleum industry employees from all major participating oil and gas companies who voluntarily joined the program at their work sites across Australia. With a similar longitudinal health surveillance system in place, the biological monitoring of workers potentially exposed to VOCs could then be tracked.

19.10 What other exposure data is available/in peer reviewed literature?

19.10.1 Historical data

The Health Risk Assessment (HRA) of an open cut coal mine in 2017 provided by RSHQ identifies hazardous materials including oils, greases, and degreasers particularly for maintenance personnel, paint, and solvents again for maintenance personnel. The qualitative risk assessment assessed these materials as being of a low risk, primarily because the exposure was expected to be short and the PPE appeared to be adequate. No exposure monitoring or biological monitoring was recommended.

Another HRA in 2019 commissioned by Petroleum and Gas Inspectorate of a workover rig and hybrid coil drilling operation, considered hazardous chemicals, mainly inorganic compounds, though fuels, oils, greases, and degreasers were mentioned. A number of activities were observed that increased the risk of worker exposure, including applying chemicals to hot surfaces which increased the volatilisation of the chemical, and decanting liquids into smaller unlabelled containers. There was minimal use of spray paints. The qualitative risk assessment ranked the potential exposure as low risk except for the derrickman where the risk was significant.

A HRA carried out in 2020 commissioned by the Petroleum and Gas inspectorate of a biogas power generation facility noted the use of oils and degreasers. The risk assessment ranked the potential risk as low, due to limited exposure.

A similar HRA carried out at a second biogas power generation facility and sewerage treatment plant, identified four 210 l drums of unknown chemical, that may have been engine coolant. No other comments were made on potential hazardous chemicals, other than the use of contractors to service and maintain the gas engine and generator and thus associated chemicals.

RSHQ provided a copy of a 2017 HRA of an open cut coal mine. A number of potential health hazards were identified, including refined hydrocarbons (oils and greases etc) and volatile organic compounds (such as acetone, acetic acid, naphtha, diethylene glycol and white mineral oil). The consequence ranking of the refined hydrocarbons was 3 and VOCs was 4 on a scale of 1—5 where 5 is catastrophic). The qualitative risk assessment identified that mobile and field maintenance personnel, workshop personnel and servicemen were at moderate risk from refined hydrocarbons, PPE being the main protection, and laboratory staff were at low risk from VOCs.

A 2017 HRA of a gold mine was provided by RSHQ. It was noted that plant maintenance personnel could be exposed to chemicals including hydrocarbons, most of which were labelled as non-hazardous. VOCs were not included in the qualitative risk assessment.

Pierrehumbert G et al (2002) studied the impact of human variability on the biological monitoring of exposure to toluene, phenol, lead and mercury and found that toluene uptake varied significantly between individuals with the same exposure.

19.10.2 Current data

The only data available for the preparation of this report consists of the following case studies:

- Mine Safety Alert NO. 393 (2 July 2021) by RSHQ reports that a worker undertaking spray painting inside the revolving frame of a dragline (a confined space), became unresponsive and was rescued. A second worker who assisted with the rescue had to be rescued as well. The report notes that there have been previous incidents in the past. It is believed that the worker was overcome by airborne solvent vapours. The affected workers were transported to hospital for medical assessment and released a short time later without any diagnosed health effects attributed to the exposure event.

- Mine Safety Alert 196 (22 May 2008) reports a mine worker suffering chemical burns to eyes due to high pressure fluid release (a mixture of sulphuric acid, phenol and phenolsulphonic acid). Immediate treatment by paramedics prevented any serious harm.

- Mine Safety Alert 233 (15 September 2009) reported that two workers were exposed to elevated concentrations of vapours containing 1 Bromopropane from an electric motor cleaning solution that was poured onto a hot gearbox. Both workers suffered respiratory irritation and one suffered nervous disorders.

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Welding fumes

20. Welding fumes

20.1 Overview

Summary of the health effects presented by the risk
Potential health hazards may be caused by either the fume/particles generated during welding/cutting processes, mining, and processing of metal ores and/or the gases generated during the processes. There are both short-term and long-term health impacts from welding fume. In general fume has a much smaller particle size distribution than dusts. Short-term effects impact health related LTI for workers because of: ► Metal fume fever ► Exposure to ozone ► Exposure to nitrogen oxides Long term effects impact: ► Respiratory system ► Nervous system ► Cardiovascular system ► Carcinogenic effects
What we know about the risk (available data and evidence from RSHQ and other sources)
► The HRAs provided by RSHQ identified that welding fume was a potential risk but did not quantify the risk, and, as such, they tell us very little about the actual exposure of workers to welding/metal fume or metal dusts ► The research outlined in this report indicates that internationally there is a trend to not to treat welding/metal fume as a total dust ► The focus is on the components of that dust especially as the International Agency for Research on Cancer (IARC) has classified welding fume as a carcinogen ► Additionally, there is increasing concern over the nanoparticles associated with welding fume ► Safe Work Australia has proposed to reduce the Workplace Exposure Standard for many of the components of fume and dust by, some case up to four orders of magnitude. This may necessitate a major overhaul of control practices

How we can learn more about the impact of this risk in the resources sector in Queensland
The literature indicates the potential to include biological monitoring as a method for assessing worker exposure to welding/metal fume and dusts containing metals. There is also a trend to reduce allowed exposure levels for a number of metals and remove the focus on the overall fume/dust. The need to reduce allowed worker exposure should initiate a review of the adequacy of current risk controls. The number of workers undertaking welding at individual work sites is small and thus exposure monitoring would need to agglomerate measurements from a number of sites to be statistically significant. Biological monitoring as part of health surveillance may be an effective alternative. By contrast there is a large cohort of workers who are potentially exposed to metals in ore and during the processing of that ore. In this case exposure monitoring should be statistically significant and allow trends over time to be established and identify those SEGs most at risk. Biological monitoring should still be considered as it is directly linked to actual exposure and adverse health effects.

20.2 What is the health hazard?

Potential health hazards may be caused by either the fume/particles generated during welding/cutting processes and/or the gases generated during the processes. Dusts containing metals can also be generated during the mining and extraction of metals from ores.

The focus of this chapter is on welding fume as this has greater potential for harm than metal-containing dusts due to the smaller particle sizes and proximity of the worker to the source of the hazard.

The health impacts of the material once absorbed into the body are the same. For the potential impacts due to dust, per se, refer to chapter 18 - Respirable Dust and Other Particulates. For the potential impacts relating specifically to lead refer to chapter 11- Lead. For the potential impacts associated with the various types of radiation, refer to chapter 16 - Non-Ionising Radiation, or to chapter 10 - Ionising Radiation.

20.2.1 Welding

In the Safe Work Australia code of practice on welding, it is described as:

"Welding is the process of permanently joining two or more materials together, usually metals, by heat, or pressure or both. When heated the material reaches molten state and may be joined together with or without extra filler materials being added. Thermoplastics, for example, can be welded together using a suitable heat source to form permanent joins.

Many different energy sources can be used for welding including gas flames, electric arcs, electric resistance, lasers, electron beams, friction, molten metal baths and ultrasound.

Welding includes joining methods as diverse as spot welding, resistance welding, forge welding, friction welding, braze welding, brazing, soldering and explosion welding.

Welding is a potentially hazardous activity and precautions are required to avoid electrocution, fire, and explosion, burns, electric shock, vision damage, inhalation of poisonous gases and fumes, hearing loss and exposure to intense ultraviolet radiation. (Safe Work Australia, 2020)

The potential health impacts from this work are derived from worker exposure to toxic gases generated during the welding process and/or metals contained with the fume generated by the melting of the electrodes, filler materials and the metals to be welded.

In Manual Metal Arc Welding (MMAW) core and filler metals are usually made of alloy similar in chemical composition to the materials being welded. The most commonly used material is mild steel. Special steels may contain chromium, nickel, molybdenum, aluminium, cobalt, vanadium, or tungsten. Stainless steel electrodes may contain up to 26 per cent chromium and 21 per cent nickel. Manganese as high as 14 per cent may also be present in certain types of steel electrodes, for example, high-manganese hard facing electrodes. High-chromium hard facing electrodes may contain up to 30 per cent chromium, present as chromium metal and chromium carbides.

MMAW electrodes are coated with a complex mixture of materials which, by melting and chemical decomposition, provide the following functions:

- A non-oxidising atmosphere (cellulose, carbonates)
- Optimum weld and weld pool metallurgy (various metals or their oxides, calcium fluoride)
- Slag formers (clays and oxides of titanium, silicon, manganese, and magnesium)
- Additional charge carriers to the plasma (readily ionisable elements such as sodium, potassium, and calcium from their compounds)

Electrode coatings may also include ferro-manganese, ferro-vanadium, and ferro-silicon. In addition, the following agents are used in manufacturing electrodes:

- Moulding agents, such as aluminium and magnesium silicate
- Extruding agents, such as starch, glucose, and methyl cellulose
- Binders, such as potassium and sodium silicate
- Fibrous materials, such as mica (asbestos is not used now)

Coatings of low-hydrogen electrodes have a high fluoride content. Electrode coatings in certain instances may have substantial amounts of metallic constituents added which contribute to the weld deposit, for example, iron, manganese, chromium, and nickel.

Hot work— where cutting of metal is undertaken using similar devices will also generate metal fume.

20.2.2 Mining metal ores

The mining process of metal ores may generate particles containing hazardous components in both the inhalable and respirable particle size range.

20.2.3 Processing metal ores

Processing metal ores can generate a wide range of particles and fumes due to the nature of the processes involved. Preparing the ores for mineral extraction can generate particulate matter. The processing may involve smelting and/or treatment with chemicals. These processes may generate fume containing metals and/or metal compounds as well as vapours from solvents and the chemicals used to extract the ore. Organic vapours will be dealt with under a separate topic.

20.3 What are the health effects/consequences of exposure?

Appendix B of the Safe Work Australia code of practice outlines examples of the types of fume typically released during welding. The hazard persists if these compounds exist in any dust that is inhaled or ingested. The information is summarized in the table below.

Table 45: Fumes released during welding and associated health effects

Fume type	Health Effect
Aluminium	Respiratory irritant
Beryllium	Metal Fume Fever. A carcinogen. Other chronic effects include damage to the respiratory tract.
Cadmium Oxides	Irritation of respiratory system, sore and dry throat, chest pain and breathing difficulty. Chronic effects include kidney damage and emphysema. Suspected carcinogen.
Chromium	Increase risk of lung cancer. Some individuals may develop skin irritation. Some forms are carcinogens (hexavalent chromium)
Copper	Acute effects include irritation of the eyes, nose and throat, nausea and 'Metal Fume Fever''.
Fluorides	Acute effects include irritation of the eyes, nose, and throat. Long term exposures may result in bone and joint problems. Chronic effects also include excess fluid in the lungs.
Iron oxides	Siderosis—a benign form of lung disease caused by particles deposited in the lungs. Acute symptoms include irritation of the nose and lungs. Tends to clear up when exposure stops.
Lead	Chronic effects to nervous system, kidneys digestive system and mental capacity. Can cause lead poisoning. Ototoxic and therefore risk of hearing loss.
Manganese	'Metal Fume Fever'. Chronic effects may include central nervous system problems. Ototoxic and therefore risk of hearing loss.
Molybdenum	Acute effects are eye, nose and throat irritation, and shortness of breath.
Nickel	Acute effect is irritation of the eyes, nose, and throat. Increased cancer risk has been noted in occupations other than welding. Also associated with dermatitis and lung problems.
Zinc oxides	'Metal Fume Fever''
Carbon Monoxide—formed in arc	Absorbed readily into bloodstream, causing headaches, dizziness, or muscular weakness. High concentrations may result in unconsciousness and death. Ototoxic and therefore a risk of hearing loss.
Hydrogen Fluoride—from decomposition of rod coatings	Irritating to the eyes and respiratory tract. Overexposure can cause kidney, bone, and liver damage. Chronic exposure can result in chronic irritation of the nose, throat, and bronchi.
Nitrogen Oxides—formed in arc	Eye, nose, and throat irritation in low concentrations. Abnormal fluid in the lung and other serious effects at higher concentrations. Chronic effects include lung problems such as emphysema.
Oxygen deficiency—caused by air being displaced by shielding gases	Dizziness, mental confusion, asphyxiation, and death
Ozone—formed in the arc	Acute effects include fluid in the lungs. Very low concentrations (e.g. 1 ppmv) cause headaches and dryness of the eyes. Chronic effects include significant changes in lung function.
Phosphine—reaction of rust inhibitor with welding radiation	Irritant to the eyes and respiratory system, can damage kidneys and other organs
Aldehydes - vaporizing of coatings or degreasing solvents	Irritant to the eyes and respiratory tract.

Fume type	Health Effect
Diisocyanates–PUR paint break- down	Eye, nose, and throat irritation. High possibility of sensitization, producing asthmatic or allergic symptoms, even at very low temperatures.
Phosgene–break-down of degreasing solvents	Severe irritant to the eyes, nose, and respiratory system. Symptoms may be delayed.

(Safe Work Australia, 2020).

Metal fume fever (MFF) has clinical symptoms which include fever, chills, myalgia, chest pain, non-productive cough, metallic taste in the mouth, leukocytosis, headache, and malaise. These clinical features are similar to those caused by respiratory viruses such as influenza or the common cold, which are seen frequently in general practice and can be misdiagnosed if an occupational history is not taken or the differential diagnosis not considered. Symptoms present within 48 hours of exposure and resolve by 1–2 days (Wong et al, 2012).

20.4 Who is exposed? And how are they exposed?

20.4.1 Welding/metal fume

Any person undertaking welding or cutting or being in close proximity to welding. Any person in close proximity to smelting of metal ores.

20.4.2 Particulate matter

Any worker participating in the mining or extraction of metalliferous ores or in the processing of the ores.

20.5 What are the current QLD regulatory requirements for the management of the hazard?

For the potential hazards due to dust, refer to chapter 18 - Respirable Dust.

Some metal dusts and fumes are classified as hazardous chemicals by Safe Work Australia and under the CMSHR 2017 and MQSHR 2017 due to their GHS classification and as such are covered by the appropriate sections of the CMSHR 2017, MQSHR 2017 and WSHR 2011.

Part 7 of the CMSHR 2017 and the MQHSR 2017 describes Hazardous Chemicals and dangerous goods. The subdivisions and sections describe:

- The meaning of hazardous chemical and dangerous goods
- The need for the Site Senior Executive (SSE) to maintain a register of hazardous chemicals and dangerous goods
- The requirements for manufacturers, suppliers, and importers to mark and label substances
- The need for the SSE to ensure that hazardous chemicals and dangerous goods are correctly marked and labelled
- The SSE must ensure that a hazardous chemical or dangerous good selected for use at the mine does not create an unacceptable level of risk to a person when used, handled, or stored under standard work instructions

- The SSE must ensure that the mine has standard work instructions (SWI) for using, handling, or storing hazardous chemicals or dangerous goods
- The risk at a mine relating to the handling or storing of a hazardous chemical or dangerous goods must be managed
- The SSE must ensure that appropriate monitoring in relation to a hazardous chemical or dangerous goods is carried out as part of any SWI or other procedure that applies to monitoring
- The SSE must ensure that the mine has a SWI for dealing with leaks and spills
- The SSE must ensure that the mine disposes of hazardous chemicals or dangerous goods appropriately

Exposure to hazardous chemicals that cause or have the potential to cause a significant adverse effect on the safety or health of a person is classified as a high potential incident under CMSHR 2017 Schedule 1C and MQSHR 2017 Schedule 1. No HPI have been reported in the data supplied by RSHQ relating to these chemicals.

Schedule 6 for both sets of regulation list general body concentrations for some chemicals relevant to this topic (apparently only applicable to underground mines in the CMSHR 2017):

- Carbon Monoxide long-term ELC 30 ppmv
- Nitric Oxide LTELC 25 ppmv
- Nitrogen Dioxide LTELC 3 ppmv Max ELC 5 ppmv
- Nitrous Oxide LTELC 25 ppmv
- Sulphur Dioxide LTELC 2 ppmv Max LEC 5 ppmv
- Welding fume LTELC 5 mg/m^3

Division 3 and subsidiary sections of the MQHR 2017 outline the requirements for health surveillance for the non-coal mining sector. Health surveillance is required if the SSE reasonably believes or ought to reasonably believe that exposure to a hazard at the mine may cause or result in an adverse health effect under the worker's work conditions and either there exists a valid technique capable of detecting signs of the health effect, or a valid biological monitoring procedure is available to detect the changes from the current accepted values for the hazard.

S 139 describes the requirements to remove any affected worker from the work environment. S 140 describes the use of PPE to manage the exposure if a mine cannot prevent or reduce the exposure by other means.

Subdivision 3 of Division 2 of the CMSHR 2017 describes the requirements for the Coal Mine Workers Health Scheme, which includes similar requirements to the above. S 49 specifically requires that the mines Safety and Health Management System must provide for periodic monitoring of the level of risk from hazards that are likely to create an unacceptable level of risk. It also requires the employer to ensure that the workers' exposure to the hazard is periodically monitored to assess the level of risk to the worker if the worker is exposed to a hazard at a coal mine.

CMSHR -1 Health assessment form lists under question 1.5 Specific coal mine worker position requirements or hazard exposures section (c) Coal mine worker may potentially be exposed to a list of specific hazardous chemicals including:

- Oils, greases
- Solvents
- Phenols
- Isocyanates
- Acids
- Alkalis
- Cement, grout, stone dust
- Detergent, hand cleaners
- The medical examination includes assessment of the skin

Schedule 1C lists a number of notifiable diseases mainly relating to respiratory issues but also including cancers (Schedule 1 in the CMSHR 2017).

Schedule 5 refers to general exposure limits for hazards deferring to the National Occupational Health and Safety Commission (NOHSC, 1985-2005) document—Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (1995). Note this document has been superseded by the Safe Work Australia Workplace Exposure Standards for Airborne Contaminants, last issued 2019 (presently undergoing review).

Recognised Standard 17, Recognised Standard for Hazardous Chemicals under the CMSHA, 1999 is a comprehensive document aimed at assisting coal mines in managing the risks associated with hazardous chemicals. Its contents include:

- Classification and labelling of workplace hazardous chemicals
- Manifests and placarding of hazardous chemicals and dangerous goods
- Preparation of safety data sheets (SDS) for hazardous chemicals
- The content of the SDS including:
  - Hazard identification
  - Composition and information on ingredients
  - First aid measures
  - Firefighting measures
  - Accidental release measures
  - Handling and storage

- Exposure controls and personal protection
- Exposure control measures
- Biological monitoring
- PPE
- Physical and chemical properties
- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information

QGL03—Guideline for Hazardous Chemicals (July 2019) issued by the then Department of Natural Resources, Mines and Energy, outlines the processes for safe acquisition, storage and use of hazardous chemicals in general under the MQHSA 1999. This mirrors RS-19.

The controls required depend upon the specifications outlined in the safety data sheets (SDS) supplied for the hazardous chemical. It is therefore vital that the SDS are accurate and comprehensive enough to permit effective management of the risk. Chapter 11 of the guideline outlines these requirements. It lists more than 120 groups of substances, or families, that should be used to ensure consistent labelling of hazardous chemicals.

Form 28, Hazardous chemical health report, outlines the reporting requirements for any person being assessed for potential adverse health effects due to hazardous chemicals. This form must be sent to WHSQ.

In 2013 WHSQ issued a code of practice for managing the risks associated with hazardous chemicals in the workplace. This document aligns with the Safe Work Australia code of practice described below (WHSQ, 2013).

Exposure to hazardous chemicals is managed under the Work Health and Safety Regulation 2011 for work sites not covered by CMSHR 2017 or MQSHR 2017. Schedule 14 of this regulation outlines the requirements for health monitoring (Division 6, sections 368 to 378) for a range of chemicals including:

- Arsenic
- Cadmium
- Chromium
- Isocyanates
- Mercury

- Thallium
- Lead

Health monitoring requirements may include:

- Demographic, medical and work history
- Records of personal exposure
- Physical examination with emphasis on areas where chemical has impact e.g. respiratory system, peripheral nervous system, or skin
- Urinary/blood analysis

Workplace Health and Safety Queensland issued a Code of Practice in 2021 on Welding Processes. This document is very similar to the SWA Model Code of Practice (see below for details) except that it references the state legislation.

There is an Australian Standard AS/NZ 2885.2:2020, Part 1 related to production welding, and Part 2 that governs welding of pipelines—Gas and liquid petroleum. Section 2 of each part describes the overall safety requirements.

20.6 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

In June 2021, the NSW Resource Regulator replaced MDG 25-Guideline for Safe Cutting and Welding in Mines (2003) and MDG25 TR-Technical Reference Material for Safe Cutting and Welding at Mines (2003) with a Technical Reference Guide—Hot Work (Cutting and Welding) at Mines and Petroleum Sites (RR, 2021).

This is a very detailed document dealing with all elements of Hot Work, including Hot Work management, which details the processes to be followed in developing a Hot Work Management System, from hazard identification, through risk assessment, risk management, controls, instruction and training, supervision, monitoring, review, etc.

In addition, there are chapters that outline specific technical details and problems with:

- Gas cutting, heating, and welding equipment
- Electric welding
- Grinding, cutting and abrasive discs
- Specific areas
- Hazardous areas
- Confined spaces
- Enclosed and sealed spaces
- Working at heights

- Underground coal mines

Under the *Model Work Health and Safety Act 2011* (WHSA, 2011), Safe Work Australia have issued a Code of Practice for Welding Processes revised in 2020, aimed at providing practical guidance for persons conducting businesses or undertakings (PCBU) on how to manage health and safety risks associated with welding.

The Code outlines the required risk management process, specific hazards and control processes and other hazards and control measures, as well as the requirements for health monitoring. It identifies welding fume total fume concentration as well as individual fume components that should be considered with reference to the Workplace Exposure Standards for Airborne Contaminants.

The Code also stresses the need to apply the hierarchy of controls when managing the risk of exposure to welding fume. It refers to regulation 49 in the WHSR 2011 that requires that a PCBU to ensure that no person in the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture.

Further, WHSR 2011 regulation 50 requires the PCBU to undertake air monitoring to determine the airborne concentration of a substance or mixture. Lead exposure is specifically mentioned and refers to regulation 395 of the WHSA 2011 relating to the management of the risk of a worker being exposed to lead.

Section 5 describes health monitoring which refers to regulation 368 of the WHSR 2011. It requires the PCBU to undertake health monitoring that can identify changes in their health status due to exposure to certain substances. This involves the collection of data to measure exposure or evaluate the effects of exposure and to determine whether the absorbed dose is within safe levels (p36 of the code of practice). Health monitoring may include biological monitoring.

Workplace Health and Safety Queensland have issued a Code of Practice for Welding Processes in 2021 that mirrors the Safe Work Australia document.

20.7 What are the current exposure standards? (TWAs/BEIs/Health surveillance/etc.)

In general (except where noted), the Safe Work Australia Exposure Standards are applied in Queensland. The following tables show the Australian, US (various US safety and health bodies), UK and NZ time-weighted averages (TWAs), short-term exposure limits (STELs), and biological exposure indices (BEI) for welding fumes. The first three columns in the BEI table are sourced from the ILO encyclopedia (ILO,2021).

Table 46: Workplace exposure standards as of 16 December 2019

Chemical	SWA		ACGIH		OSHA		NIOSH	Worksafe NZ		HSE(UK)		
	TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	TWA mg/m^3	STEL mg/m^3	WES–TWA	WES/STEL
Aluminium (Fume)	5		1		5		5		10		4 mg/m^3 respirable	
Beryllium - carcinogen	0.002		0.00005		2	5	No safe value		0.0002		0.002 mg/m^3	
Cadmium - carcinogen	0.01		0.01		0.1	0.3	No safe value		0.004		0.025 (as Cd) mg/m^3	0.05 mg/m^3 (as Cd)
Carbon Dioxide	9000 (5000 ppmv)	54000 (30000 ppmv)	9000 (5000 ppmv)	54000 (30000 ppmv)	5000 ppmv	30000 ppmv	5000 ppmv	30000 ppmv	9000 (5000 ppmv)	54000 (30000 ppmv)	5000 ppmv	15000 ppmv
Carbon Monoxide	34 (30 ppmv)		25 ppmv		50 ppmv	200 ppmv	35 ppmv	200 ppmv	25 ppmv	200 pppmv	20 ppmv 30 ppmv mining	100 ppmv 200 ppmv mining
Chromium (II and III)	0.5		0.5 0.003		0.5		0.5		0.5		0.5	

Chemical	SWA		ACGIH		OSHA		NIOSH	Worksafe NZ		HSE(UK)		
Chromium (VI)	0.05		0.0002		0.005	0.1 ceiling	0.0002		0.00002		0.01	
Cobalt	0.05		0.02		0.1		0.05		0.02		0.1	
Copper dust	1		1						0.01		1 mg/m^3	
Copper fume	0.2		0.2		0.1		0.1		0.01		0.2 mg/m^3	
Diisocyanates	0.02	0.07							0.02	0.07		
Fluorides	2.5		2.5		2.5		2.5		2.5		2.5 mg/m^3	
Hydrogen Fluoride		2.6 ppmv peak not to be exceeded	0.5 ppmv	2 ppmv 2.6 ppmv peak	3 ppmv		3 ppmv	6 ppmv		2.6 peak limitation	1.5 mg/m^3	2.5 mg/m^3
Iron	5 (as oxide)		5 (as oxide)		10		5		5 (as oxide)		oxide fume 5 mg/m^3 as Fe	
	1 (as soluble salts)		1 (as soluble salts)						1 (as soluble salts)		Salts 1 mg/m^3 as Fe	

Chemical	SWA		ACGIH		OSHA		NIOSH	Worksafe NZ		HSE(UK)		
Lead As chromate	0.05		0.05 0.0002	- 0.0005	0.05		0.05		0.05		0.15 mg/m^3	
Manganese	1		0.02 0.1		5		1	3	0.2		0.05 mg/m^3 respirable 0.2 mg/m^3 inhalable	
Molybdenum	10 (insoluble cmpds)		10 (insoluble cmpds)		5		Appendix d		10 (insoluble cmpds)		5 mg/m^3 soluble	10 mg/m^3
	5 (soluble cmpds)		0.5 (soluble cmpds)		15 total 3 respirable				5 (soluble cmpds)		10 mg/m^3 insoluble	20 mg/m^3
Nickel	1		1.5 Soluble inorg cmpd 0.1 Insoluble inorg cmpd 0.2 subsulphide 0.1		1 1		0.015 0.015		0.005		mg/m^3 water soluble 0.5 mg/m^3 insoluble	
	N_2O 45 (25 ppmv)		N_2O 50 ppmv		N2O				N_2O 45 (25 ppmv)		NO_2 0.5 ppmv	1 ppmv

Chemical	SWA		ACGIH		OSHA		NIOSH	Worksafe NZ		HSE(UK)		
Oxides of Nitrogen	NO 31 (25 ppmv)		NO 31 (25 ppmv)		NO 30 ppmv		25 ppmv		NO 31 (25 ppmv)		NO 2 ppmv	
	NO2 5.6 (3 ppmv)	9.4 (5 ppmv)	NO2 0.2 ppmv		NO2 5 ppmv		1 ppmv		NO_2 1.9 (1 ppmv)		N_2O 100 ppmv	150 ppmv
Ozone	0.2 (peak limitation)		0.05ppm Heavy work 0.08ppm Moderate work 0.10ppm Light work 0.20ppm h/M/L work < 2 hours		0.1 ppmv	0.2 ppmv	0.1 ppmv		0.2 (peak limitation)			0.2 ppmv
Phosgene	0.08 (0.02 ppmv)	0.25 (0.06 ppmv)	0.1 ppmv		0.4		0.4	0.8	0.08 (0.02 ppmv)	0.25 (0.06 ppmv)	0.02 ppmv	0.06 ppmv
Phosphine	0.42 (0.3 ppmv)	1.4 (1 ppmv)	0.05 ppmv		0.4		0.4	1.3	0.42 (0.3 ppmv)	1.4 (1 ppmv)	0.1 ppmv	0.2 ppmv
Silica/silicates - carcinogen	0.05		0.025		0.05		0.05		0.05		0.1 mg/m^3	
Vanadium	0.05 (as V_2O_5)		0.05 (as V_2O_5)		0.1		0.05		0.05 (as V_2O_5)		0.05 mg/m^3 as V_2O_5	

Chemical	SWA		ACGIH		OSHA		NIOSH	Worksafe NZ		HSE(UK)		
Welding fume not otherwise classified	5	-							5	-		
Zinc	5 (oxide fume)	10 (oxide fume)	2 (oxide fume)	10 (oxide fume)	5		5		0.1(oxide fume)	0.5 (oxide fume)	1 mg/m^3	

Table 47: Biological Monitoring BEI and Biological Monitoring Guidance Values (BMGV)

Chemical	L and H 1993 reference values	DFG limit	L and H 1993 limit	ACGIH	Worksafe NZ	HSE
Aluminium (Fume)	1 µg/100 mL serum 30µg/g urine	200 µg/L serum end of shift	150 µg/g end of shift urine			
Beryllium	2 µg/g urine					
Cadmium	0.5 µg/100mL blood 2 µg/g urine	1.5 µg/100 mL 15 µg/l	5 µg/g	5 µg/g creatinine in urine 5 µg/L in blood	2 µg/g creatinine	
Carbon Dioxide						
Carbon Monoxide				3.5 % of hemoglobin 20 ppm in exhaled air	3.5 % of hemoglobin 20 ppmv in exhaled air	30 ppm in end tidal breath
Chromium (II and III)						

Chemical	L and H 1993 reference values	DFG limit	L and H 1993 limit	ACGIH	Worksafe NZ	HSE
Chromium (VI)		30 µg/g serum end of shift/workweek 10 µg/g increase during shift	30 µg/g serum end of shift	25 µg/L in urine	25 µg/L in urine	10 µmol/mol creatinine in urine
Cobalt	0.05 µg/100 mL serum 0.2 µg/100 mL blood 2 µg/g urine	0.5 µg/100 mL (EKA) Serum 60 µg/L blood (EKA)	30 µg/g serum end of shift, end of workweek	15 µg/L in urine	15 µg/L in urine	
Copper dust						
Copper fume						
Diisocyanates						1 µmol isocyanate-derived diamine/mol creatinine in urine
Fluorides				2mg/L in urine prior to shift 3 mg/L in urine after shift	2 mg/L prior to shift 3 mg/L post shift in urine	
Hydrogen Fluoride						
Iron						
Lead—see lead chapter for details	Blood 25 µg/100 ml ZPP in blood 40 µg/100 ml Urine 2.5 µg/g Hb ALA urine 50 µg/g 4.5 mg/g	Female < 45 30 µg/100 ml blood Male 70 µg/100 ml	40 µg/100 mL blood 40 µg/100 mL blood or 3 µg/g Hb ALA urine 50 µg/g 5 mg/g	200 µg/L in blood	20 µg/dL in blood	"action level" means a blood-lead concentration of—(a) in respect of a woman of reproductive capacity, 25 µg/dL; (b) in respect of a young person, 40 µg/dL; or (c) in respect of any other employee, 50 µg/dL;

Chemical	L and H 1993 reference values	DFG limit	L and H 1993 limit	ACGIH	Worksafe NZ	HSE
						"suspension level" means—(a) a blood-lead concentration of—(i) in respect of a woman of reproductive capacity, 30 µg/dL, (ii) in respect of a young person, 50 µg/dL, or (iii) in respect of any other employee, 60 µg/dL; or (b) a urinary lead concentration of—(i) in respect of a woman of reproductive capacity, 25 µg Pb/g creatinine, or (ii) in respect of any other employee, 110 µg Pb/g creatinine;
Manganese	Blood 1 µg/100 ml Urine 3 µg/g					
Molybdenum						
Nickel	Serum 0.05 µg/100 ml Urine 2 µg/g	45 µg/L (EKA)	30 µg/g serum			
Oxides of Nitrogen						
Ozone						
Phosgene						
Phosphine						
Silica/silicates						
Vanadium	Serum 0.2 µg/100 mL					

Chemical	L and H 1993 reference values	DFG limit	L and H 1993 limit	ACGIH	Worksafe NZ	HSE
	Blood 0.1 µg/100 mL Urine 1 µg/g					
Welding fume not otherwise classified					-	
Zinc						

EKA (Expositionsäquivalent für krebserzeugende Arbeitsstoffe)—Exposure equivalents for carcinogenic materials

Column 4 is the tentative maximum permissible concentrations from Lauwerys and Hoet 1993

Urine is per gram of creatinine

20.8 How is the hazard measured/evaluated in the workplace?

20.8.1 Current method and its limitations

Australian Standard AS 3853.1-2006 Health and Safety in welding and allied processes-Sampling of airborne particles and gases in the operator's breathing zone Part 1: Sampling of airborne particles, describes the process for assessing the exposure of a worker to particles during the welding process. It is equivalent to part of European Standard EN ISO10882 relating to inhalable fraction of airborne particles.

Welding fume is generally less than 1 micron in diameter. The technique relies upon a gravimetric sample collecting the inhalable fraction of particles within the breathing zone of the welder (inside his face shield where worn). It notes that short term measurements (15 minutes) can be undertaken where chemical agents are present that have short term exposure levels.

Measurements are to be taken during a representative number of welding episodes throughout the work period. Sampling is to be discontinued where there is potential for significant exposure to other airborne particles. Chemical agent exposure is undertaken through chemical analysis of the welding fume sample.

Australian Standard AS 3853.1-2006, *Health and safety in welding and allied processes-Sampling of airborne particles and gases in the operator's breathing zone,* Part 2: Sampling of gases, describes the process for assessing the exposure of a worker to gases during the welding process. This part of the standard also conforms to EN ISO10882, the gases can include:

- Fuel gases used in gas welding and cutting which on combustion produce carbon dioxide and carbon monoxide
- Shielding gases such as argon, helium, carbon dioxide or mixtures of these gases
- Gases produced by the action of heat upon the welding flux or slag, e.g. carbon dioxide and carbon monoxide
- Gases produced by the action of heat or ultraviolet radiation upon the atmosphere surrounding the welding arc, e.g. nitric oxide, nitrogen dioxide and ozone
- Vapours produced as a result of the thermal degradation of surface coatings in the welding or cutting of metals treated with paint or primer, sealer, or other substances such as degreasing solvents

There is no Australian Standard for determining the metal content of dusts as such and the regulations do not specify a method. The above standard (part 1) can be used.

Techniques for monitoring worker exposure to metal dusts and fumes include:

- Direct reading electrical apparatus—these are preferred where available as they can give instantaneous results and can be accurately calibrated.
- Detector tubes (short term or long term)—best used only for screening purposes due to the high level of uncertainty and selectivity compared to direct reading or laboratory techniques. These are not real time monitors but taken over a period of time.
- Indirect methods involving laboratory analysis where the sample is collected using a suitable solid or liquid sorbent.

As with the particle monitoring, the sample should be obtained within the breathing zone of the worker and inside any mask or shield that is worn.

20.9 Emerging technology/research

The NSW Resources Regulator issued a safety bulletin in November 2018 which stated through their Targeted Assessment Programs that some mine operators have not identified or acted upon this reclassification. The focus of the bulletin was on improved ventilation of the welding area and good quality PPE, such as properly fitted airstream helmets. It also highlighted the inappropriate reliance on natural or fan-forced ventilation to dilute fumes without consideration of other workers in the vicinity. It recommended that:

- Welding processes must be subject to risk assessment, and the hierarchy of controls applied to controlling the risks associated with welding fumes
- Appropriate information and training be provided to all workers at risk from welding fumes including contractors
- Appropriate PPE must be provided to at-risk workers who undertake welding work
- Mine operators should develop and implement processes to monitor and assess compliance with identified risk controls
- Occupational Hygiene assessment and monitoring programs should be expanded to incorporate worker exposure to welding fumes. (RR, 2018)

The Department of Mines, Industry Regulation and Safety issued Safety Bulletin 154 on managing the long-term exposure to carcinogenic welding fumes 24 August 2018. It notes that the current exposure standards are set based upon short term illness (metal fume fever—5 mg/m3 dust). It also said that 12 % of welding fume samples submitted to the Department exceeded the Australian Exposure Standard—for welding fume as a dust.

The bulletin explains that in other developed countries the exposure standard for welding fume as a dust was often significantly lower (1.25 mg/m^3 in Germany and 1mg/m^3 in the Netherlands). It recommended that:

- Workers be informed of the risks associated with welding activities
- Reduce exposure to welding fumes as far as practicable by using engineering controls
- Provide welders with appropriate respirators and train them in the use and maintenance of these respirators
- When welding is conducted over extended periods of time, provide supplied air or powered respirators in addition to protective clothing and UV filtering helmet

Safe Work Australia have been undertaking a review of workplace exposure standards (Safe Work Australia, 2021b). The table below outlines the values that they have proposed in comparison to the current limits. These values have been out for public comment prior to release as official WES. In almost every case there has been a significant reduction in the allowed WES. Of particular note:

- They have withdrawn the WES for welding fume as a total dust
- Beryllium has been reduced by a factor of 100

- Cadmium has been reduced by a factor of 10
- Chromium (II) and (III) reduced by just over a factor of 10
- Chromium (VI) reduced by four orders of magnitude
- Cobalt reduced by factor of 2.5
- Copper reduced by a factor of 10
- Isocyanates reduced by a factor of 200
- HF has a proposed WES TWA of 0.4 ppmv with a peak reduced to 1.6 ppmv
- Lead has been reduced by a factor of 7
- Manganese has been reduced by a factor of 50
- Molybdenum is being split up into various specific compounds as well as reducing soluble compounds by a factor of 10
- Nickel has been reduced by a factor of 10
- Nitric oxide has been reduced by a factor of 15
- Nitrogen dioxide has been reduced by a factor of 15
- Phosphine has been halved

It is probable that these proposed values will be the subject of revision after all the comments have been processed (for example: the original value proposed for silica was 0.02 mg/m^3 but this was raised to 0.05 after review). If implemented these reductions may significantly affect the level of compliance at work sites and trigger a review of control practices.

Table 48: Comparing current and proposed SWA exposure standards.

Chemical	Current SWA		Proposed changes subject to comment at review
	TWA mg/m^3	STEL mg/m^3	TWA mg/m^3 unless stated otherwise
Aluminium (Fume)	5		1
Beryllium - carcinogen	0.002		0.02µg/m^3
Cadmium - carcinogen	0.01		0.001
Carbon Dioxide	9000 (5000 ppmv)	54000 (30000 ppmv)	No change
Carbon Monoxide	34 (30 ppmv)		20 ppmv
Chromium (II and III)	0.5		0.04
Chromium (VI)	0.05		0.000007

Chemical	Current SWA		Proposed changes subject to comment at review
Cobalt	0.05		0.02
Copper dust	1		0.01
Copper fume	0.2		0.01
Isocyanates	0.02	0.07	0.0001
Fluorides	2.5		No change
Hydrogen Fluoride		2.6 ppmv peak not to be exceeded	0.4 ppmv with peak 1.6
Iron	5 (as oxide)		No change
	1 (as soluble salts)		No change
Lead chromate	0.05		0.007 0.02µg/m^3
Manganese	1		0.02
Molybdenum	10 (insoluble cmpds)		Various limits being considered for specific compounds
	5 (soluble cmpds)		0.5
Nickel	1		0.1
	N_2O 45 (25 ppmv)		50 ppmv
Oxides of Nitrogen	NO 31 (25 ppmv)		2 ppmv
	NO_2 5.6 (3 ppmv)	9.4 (5 ppmv)	0.2 ppmv
Ozone	0.2 (peak limitation)		No change
Phosgene	0.08 (0.02 ppmv)	0.25 (0.06 ppmv)	0.1
Phosphine	0.42 (0.3 ppmv)	1.4 (1 ppmv)	0.21 ppmv
Silica/silicates - carcinogen	0.05		No change (changed in 2018)
Vanadium	0.05 (as V2O5)		No change
Welding fume not otherwise classified	5	-	No recommended value
Zinc	5 (oxide fume)	10 (oxide fume)	No change

20.10 What health monitoring data is currently available to RSHQ?

20.10.1 What is the status of the data?

- RSHQ did not provide information relating to welding fume for the preparation of this report, so it is not known whether the data collected by RSHQ is either general for all welding fumes, or for specific components. RSHQ supplied de-identified blood lead measurements—refer to chapter 11- Lead for details.
- The granularity of the Workers' Compensation Data provided did not permit linking any occupational diseases with metal fume or dust exposure.
- RSHQ did not supply any measurements of workplace exposure to metals, or their ores.
- RSHQ provided a number of health risk assessments that had been undertaken for individual mines as well as a biogas power generation facility and a sewerage treatment plant.
- Welding was not identified as a task at the biogas power generation facility or the sewerage treatment plant.
- The HPI and LTI data supplied did not identify any instances of metal fume incidents or illness due to metal containing dusts.

A Health Risk Assessment (HRA) carried out at an open cut coal mine in November 2017 did identify welding as a hazardous task carried out at the mine with a consequence rating of 4—Major Chronic for boilermakers, likelihood ranking 4 -50—100% of OEL, risk score of 21 cf maximum of 25. The use of PPE reduced the risk score to 18 through the reduction of the likelihood one level, still ranked as a Major Chronic Risk. No actual exposure monitoring was undertaken. The residual risk ranking 18 placed welding fumes in the group of hazards ranked second highest.

An HRA carried out in May 2017 at a gold mine identified welding fume as one of the top four health hazards at the mine. It noted that in the previous five years no welding fume exposure measurements had been made at the mine. The HRA ranked welding fume as Major—Chronic (3). Note that unlike the previous study where a five-point scale was used a four-point scale was used for the ranking here, so the score is equivalent to the previous study, again in the second highest risk ranking category.

A 2019 study carried out at a workover rig and hybrid coil drilling operation for the Petroleum and Gas Inspectorate did identify welding fume and allied processes as a potential hazard. The hazard was confined to field maintenance/boilermaker with a risk ranking of low—due to a combination of moderate/reversible consequence ranking (3 out of 5) and a likelihood ranking of 4 (out of 5) and an overall risk ranking of Low although it appears it should have been medium.

Another HRA and Future Occupational Hygiene Monitoring Program Recommendations report of a study undertaken at an open-cut coal mine in 2017 carried out the usual qualitative risk assessment as applied above following a walk-through survey. The qualitative risk assessment ranked welding fume as a significant risk—consequence moderate/reversible (3 out of 5) and likelihood of exposure 4 out of 5. This mine had taken a total of 4 samples in 2015-2016 of which three exceeded the shift adjusted regulatory limit for welding fume, one of which returned an iron concentration within the action zone. The report recommended ongoing monitoring of welding fume for the boilermakers.

20.10.2 What does it tell us about workers' exposures?

The HRAs identified that welding fume was a potential risk but did not attempt to quantify the risk, and, as such, they tell us very little about the actual exposure of workers to welding/metal fume or metal dusts.

The information outlined above indicates that internationally there is a trend to ignore welding/metal fume as a dust and instead focus on the components of that dust especially as IARC has classified welding fume as a carcinogen. In addition, there is increasing concern over the nanoparticles associated with welding fume.

20.10.3 How could data collection and management be improved?

Since RSHQ data could not be made available for the preparation of this report, improvement recommendations for data collection and management cannot be made here.

The literature indicates the potential to include biological monitoring as a method for assessing worker exposure to welding/metal fume and dusts containing metals.

The number of workers undertaking welding at individual work sites is small and thus exposure monitoring would need to agglomerate measurements from a number of sites to be statistically significant. Biological monitoring as part of health surveillance may be an effective alternative.

20.10.4 What other exposure data is available/in peer reviewed literature?

The research outlined below is broadly in agreement with the proposed changes to the WES put forward by Safe Work Australia above.

The HSE in the UK has abandoned an OEL for welding fume as such, and instead focuses on the individual components of the fume.

October 2017 IARC concluded that exposure to welding fumes causes lung cancer in workers. The studies that this conclusion was based upon showed the cancer risk was relevant to both mild steel and stainless-steel welding. Lung cancer risks were observable at very low exposure risks below 1 mg/m^3 and perhaps below 0.1 mg/m^3 averaged over a working lifetime. The paper recommends the review of current exposure limits to ensure that they are protective. The risk relates to the total welding aerosol rather than the hexavalent chromium that is present in stainless steel welding. The current UK limit for welding fume as Fe in inhalable aerosol is 5 mg/m^3 for an 8-hour shift and 10 mg/m^3 for a 15-minute average (Cherrie et al, 2020).

Koh et al (2015) studied the relationship between welding fume exposure and COPD in Korean Shipyard welders. They found that there was an association between welding fume exposure and increased risk of COPD, at levels of exposure of greater than 3.42mg/m^3-years (Koh et al, 2015).

In 2003 ACGIH withdrew the TLV-TWA for welding fume as total particulate as there was a need to focus on what was in the fume, e.g. hexavalent chromium, nickel, and respirable manganese. Harris (2019) argues for separate OELs for each type of fume based upon its constituents. IARC classification applies to all welding fume (Harris, 2019).

Roach (2018) undertook an analysis of pulmonary function testing when comparing smokers to non-smokers. This analysis showed that smoking has a synergistic effect when combined with welding fume exposure on pulmonary decline (Roach, 2018). In a study of welders and lung cancer risk by Pesch et al (2019), welders were 55% more likely to get lung cancer than control population (if fume > 1.8 milligrams/m3 years), 85% more likely if exposed to high levels of Chromium VI (>

1.4 micrograms/m^3 years) and 60% more likely if exposed to high levels of Nickel (>9 micrograms/m^3 years). The odds ratio more than doubled in each case if the welder was a smoker (Pesch et al, 2019).

Dueck et al (2021) studied the individual metals present in welding fumes in the learning environment of apprentice welders. Little data is available for metals other than vanadium and antimony. HRA showed that the apprentices were at risk of overexposure to manganese. Potential health impacts depend upon particle size as well as chemical composition with ultrafine and fine particles depositing in the alveoli making it difficult to remove them. The study was on mild steel welding using gas metal arc welding. Most metals were detected at levels less than the 8 Hour TWA, however respirable manganese exceeded the TWA on occasion (Dueck et al, 2021).

Persoons et al (2014) undertook a trial of a biomonitoring strategy using analysis of urine for chromium, nickel, and manganese for welders. Values were compared to occupational health guidance values. All measurements were below the occ health guidance values (Persoons et al, 2014).

McCarrisk et al studied the impact of filler choice on the toxicology of nanoparticles generated during welding. Fume particles generated with tested flux-cored wire (FCW) were found to be more cytotoxic compared to particles generated by solid wire or metal cored wire (MCW). FCW were also more potent in causing generation of reactive oxygen species and DNA damage. This study refers to in vitro studies showing that stainless steel welding fumes are significantly more toxic and reactive in comparison to fumes from mild steel. Stainless steel welding fumes have also been shown to induce toxicity in vivo (McCarrick et al, 2019).

Mocevic, et al (2015) undertook a systematic review with meta-analysis of the risk of ischemic heart disease (IHD) following occupational exposure to welding fumes. They found that the data was too limited to evaluate the risk of IHD related to specific welding characteristics. However, acute myocardial infarction RR of 1.69 and IHD overall was R 1.09–1.39 using an internal reference group and 1.08 using an external reference group. Several studies indicate that welding is associated with an increased risk of IHD, however, bias, and confounding factors (age, gender, social class, and smoking) cannot be ruled out with reasonable confidence (Mocevic, et al, 2015).

Riccelli et al (2020) undertook a literature review of welding fume research. In vitro and In vivo methods were used to understand welding fume pathogenesis. Welding fumes are composed of fine and ultrafine particles, which may reach the distal airways and represent a risk factor for respiratory disease. Particle size distribution varies across welding techniques. Thermodynamic diameter of particles more important than aerodynamic diameter for nanoparticles as drag forces are absent and they can diffuse with high efficiency throughout entire respiratory tract. TIG welding generates the most ultrafine particles (<0.14 µm)—nearly 70% by mass and also the finest (>2.09 µm)—10% by mass (Riccelli et al, 2020).

Gracyk et al, 2016) found that TIG welding generates low mass emission rates in comparison to other types of welding but generates a large majority of nanoscale particles. TIG fume particles may produce reactive oxygen species which can react quickly alveoli tissue, causing damage to cell components and launch a cascade of local and systemic responses which may lead to disease. This study identified biomarkers that could be used to monitor exposure to TIG fume (Gracyk et al, 2016).

Manganese is a common component of welding fume and is an established neurotoxicant. Racette et al studied shipyard and fabrication welders. Overall, 15.6% of welding exposed workers had parkinsonism as opposed to none of the reference group. Prior studies have delivered mixed results and the association is controversial (Racette et al, 2012).

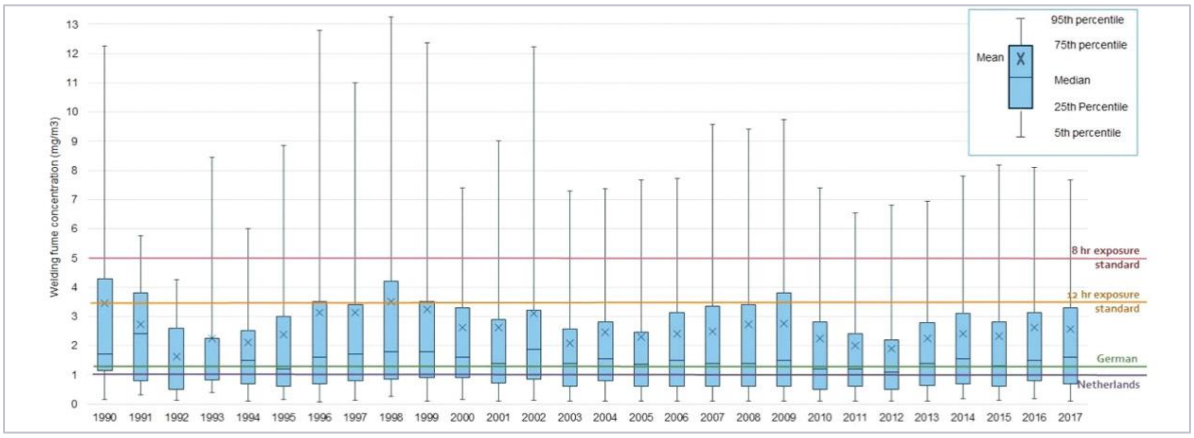
Cosgrove undertook a review of the literature on Pulmonary Fibrosis (PF). He found consistent evidence that the consequence of exposure to steel welding fume at high levels for a prolonged period of time is a type of PF which may develop into desquamative interstitial pneumonia, at levels in excess of 100 mg.years/m^3 (Cosgrove, 2015).

Shen et al (2018) undertook analysis of plasma samples taken pre and post shift from 52 boilermakers. The top two disease-associated pathways were systemic inflammation-related diseases including rheumatoid arthritis and systemic lupus erythematosus Metabolic changes were observed associated with inflammation. These changes were also linked to smoking. These metabolite changes may be potential health monitoring biomarkers. Of the 693 metabolites detected 113 were significantly altered, 78 up and 35 down (Shen et al, 2018).

20.10.5 Historical data

DMIRS has published welding fume data by annual average for fume (total fume) for the years 1990 to 2017. It is depicted below. There is no real trend over time with the average exposure generally sitting below the 5 mg/m^3 standard. A small percentage exceeded the standard value.

Figure 28: WA DMIRS annual welding fume exposures (DMIRS,2018).



There were 57 notifiable welding related incidents in the WA Mining Industry in 2018, with only one of these related to potential exposure to toxic gas or fumes where persons are affected (DMIRS, Monthly Safety and Health Snapshot—Welding hazards, May 2018).

20.10.6 Current data

A number of studies outlined above indicate the state of current monitoring of exposure of workers to welding fume.

No recent systematic studies of workers to metal dusts in the resource sector could be located.

A Study of Finnish men found that there was an increased risk of lung cancer due to cumulative exposure to iron and welding fume. Sheet metal workers were at the highest risk (1.81). The risk of lung cancer to welders was approximately 1.15, for squamous-cell carcinoma 1.55 (Siew et al, 2008).

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Whole-body vibration

21. Whole-body vibration

21.1 Overview

Summary of the health effects presented by the risk

Long term exposure to elevated levels of whole-body vibration associated with the operation of mobile equipment has been identified as a significant contributor to the subsequent development of back pain [1-4]. It has also been directly or indirectly linked as a contributor to adverse health effects on the cardiovascular, nervous, digestive, metabolic, endocrine, and reproductive systems [5-6]. The effects of whole-body vibration exposure are likely to be cumulative, taking several years to occur.

What we know about the risk (available data and evidence from RSHQ and other sources)

Recent research [11-20] indicates operators of mobile earth moving equipment at both surface and underground Australian coal mines are exposed to whole-body vibration exposures often within and above the ISO 2631.1 recommended health guidance caution zone (HGCZ). The findings indicate whole-body vibration exposure is widespread across industry, is infrequently measured and poorly managed. Monitoring and managing whole-body vibration exposures is challenging.

There is minimal data available for the assessment of this risk to workers in the mining and resource sectors in Queensland. The whole-body vibration exposure data provided by RSHQ consists of some LTI reports and workers' compensation claims. More data (quantitative and qualitative) is needed to evaluate the magnitude and variability in exposures in the Queensland resources sector to whole-body vibration, and the hazard is presently likely to be underestimated.

How we can learn more about the impact of this risk in the resources sector in Queensland?

It is recommended that:

- Organisations within the Queensland resources sector specifically include whole-body exposures in their health risk assessments
- Regular, long duration monitoring of operator exposures to whole-body vibration should be undertaken as part of site based whole-body vibration management plan

This information would provide the opportunity for evidence-based decisions regarding effective control measure implementation. Whole-body vibration management is an iterative and on-going process.

21.2 What is the health hazard?

Whole-body vibration is a common hazard in mining and resources industries due to the heavy machinery operators use. Whole-body vibration results from transmission of environmental vibration waves to the human body. The human body is not exposed to a single wave, but a multitude of simultaneous waves of differing frequency, magnitude, and direction.

21.3 What are the health effects/consequences of exposure?

Long term exposure to elevated levels of whole-body vibration associated with the operation of mobile equipment has been identified as a significant contributor to the subsequent development of back pain [1-4]. It has also been directly or indirectly linked as a contributor to adverse health effects on the cardiovascular, nervous, digestive, metabolic, endocrine, and reproductive systems [5-6]. The effects of whole-body vibration exposure are likely to be cumulative, taking several years to occur.

21.4 Who is exposed?

Within coal mines, metalliferous mines and quarries, most operational workers are routinely exposed to whole-body vibration and in many cases are likely to be exposed to levels exceeding the Health Guidance Caution Zone (HGCZ) described in ISO 2631.1. [7] AS2670.1 mirrors this standard. For example, a range of mobile plant and equipment such as bulldozers, shovels, excavators, graders, water carts, and haul trucks are used at surface mines and quarries, while underground mining operations generally utilise shuttle cars, load-haul-dump vehicles, graders and personnel transport vehicles. Heavy equipment operation frequently involves maintaining awkward postures (including static sitting) for prolonged periods of time, as well as frequent spinal twisting, which exacerbates operator exposure risks.

The potential consequences of exposures to whole-body vibration during pregnancy are unknown. A widely cited review by Seidel [8] concluded that "increased risks of abortions, menstrual disturbances, and abnormalities of positions can be assumed to be associated with long term exposures to whole body vibration. A safe limit to avoid a higher risk cannot be derived from literature". Recommendations for women to avoid vibration exposures are, however, consistently found in guidance materials.

21.5 How are they exposed?

Whole-body vibration exposures experienced by equipment operators are a function of many variables including equipment design; seat design, condition, and adjustment; roadway conditions; vehicle maintenance; activity undertaken; and driver behaviour. Many of these variables are dynamic in nature, varying over time periods ranging from hours (activity undertaken), days (roadway conditions, seat adjustment), months (vehicle maintenance), or years (equipment design). Managing such a dynamic hazard is currently challenging for sites because frequent and systematic measurement of whole-body vibration levels is rarely undertaken.

21.6 What are the current QLD regulatory requirements for the management of the hazard?

Queensland has separate *Mining Health and Safety Legislation* (2017) for both coal and metalliferous mines, and quarries, which includes a requirement for sites to have in place a Health and Safety Management System, with whole-body vibration specifically included in the identified risks requiring management. Designers, manufacturers, importers and suppliers of plant, substances and structures have duties under sections 22-25 of the WHS Act. These duties may be summarised as a duty to ensure, so far as is reasonably practicable, that the plant, substance or structure is without risks to the health and safety of people at a workplace who use it for a purpose for which it was designed or manufactured.

Sites are required to undertake a risk assessment when making modifications to equipment in use.

The Queensland mining inspectorate issues Guidance Notes to assist mine sites to identify and manage specific workplace hazards, however a guidance note on whole body vibration has not been produced. The *Petroleum and Gas Act (Production and Safety), Regulation (Safety)* 2018, and the Work Health and Safety Act provide legislative obligations for the petroleum and gas sector, but no specifics on managing whole body vibration are provided.

21.7 What are the trends in other jurisdictions (mining and non-mining) for the management of this hazard?

NSW

New South Wales' mining legislation includes the *Work Health and Safety (Mines) Regulation* (2014), where a Health Management Plan is required. New South Wales legislation requires a Safety Management System and a Health Management Plan for manual tasks, which includes whole-body vibration. The regulator provides mining design guidelines (MDGs) which are similar in structure and intent to Queensland regulator Guidance Notes.

The New South Wales mining regulator has issued MDG15 "*Guidelines for Mobile and Transportable Equipment for Use in Mines"* (NSW DPI 2002) which stipulates in clause 3.6.3 that:

> "Adequate preventative measures shall be taken to prevent excessive vibration being transmitted to the Operator during the operation of any equipment. The transmitted vibration during operations shall not exceed the levels specified by AS2670.1. 'Evaluation of human exposure to whole-body vibration - General requirements" and,

The NSW regulator has also released *Mining Design Guideline 1009* (2015) which provides guidance for "Managing road and vehicle operating areas in underground coal mines". The document makes specific mention of operator exposure to whole-body vibration, highlighting the awareness and concern that has been placed on identifying and managing site-based sources of whole-body vibration.

21.7.1 WA

The Western Australian Department of Mines and Petroleum (DMP) does not specifically regulate identification, assessment or control of risks associated with whole body vibration but does refer to the *National Code of Practice for the Prevention of Musculoskeletal Disorders from Performing Manual Tasks at Work*. Appendix 3B provides guidance on controls to eliminate or minimise the risks from exposure to vibration during manual tasks. The DMP has issued guidance on whole-body vibration – Manual tasks in mining fact sheet. No 6: Whole-body vibration.

21.8 What are the current exposure standards?

In Australia there are no regulatory limits for whole-body vibration exposures, however, ISO2631.1 (AS2670.1 mirrors ISO2631.1) provides guidance.

21.8.1 ISO2631.1 (AS2670.1 mirrors ISO2631.1)

The standard identifies acceleration as the measurement quantity by which to assess whole-body vibration and provides instruction as to the direction, location, and duration of measurements. No explicit instructions regarding the frequency or duration of measurements are provided, however, the standard indicates measurement should be "sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures that are being assessed".

ISO standard 2631.1 *"Evaluation of Human Exposure to Whole-body Vibration: Part 1- General Requirements"* (ISO 1997; ISO 2010) describes procedures for the measurement of whole-body vibration. **Two principal methods of describing frequency-weighted acceleration amplitudes are defined:** (i) the root mean square (r.m.s.); and (ii) the Vibration Dose Value (VDV), a cumulative fourth-root measure which is more sensitive to high amplitude jolts and jars. ISO2631.1 provides guidance regarding the evaluation of health effects, defining a "health guidance caution zone" (HGCZ) for both r.m.s. and VDV measures.

- For exposures below the health guidance caution zone (HGCZ) it is suggested that no health effects have been clearly documented
- For exposures within the health guidance caution zone, "caution with respect to potential health risks is indicated"
- For amplitudes greater than the health guidance caution zone, it is suggested that "health risks are likely"

For an 8-hour daily exposure assessed via the r.m.s. measure, the lower and upper boundaries of the health guidance caution zone are approximately 0.47 m/s^2 and 0.93 m/s^2 respectively.

The corresponding values for the VDV measure expressed as an 8-hour equivalent [VDV(8)] are 8.5 $m/s^{1.75}$ and 17 $m/s^{1.75}$ [8].

SafeWork Australia [9] has published guidance information on vibration but refers to the EU Directive [10]. *The European Union directive 2002/44/EC* (European Union Parliament, 2002) provides another method of evaluating whole-body vibration exposure. It sets an Exposure Action Value (EAV) above which employers are required to control whole-body vibration risks and an Exposure Limit Value (ELV) above which workers must not be exposed. It provides EAV thresholds of 0.5m/s^2 (r.m.s.) and 9.1$m/s^{1.75}$ (VDV) and ELV thresholds of 1.15 m/s^2 (r.m.s.) and 21$m/s^{1.75}$ (VDV) respectively.

There are differences between the r.m.s. and VDV threshold values provided for the EAV and the EVL and for the health guidance caution zone threshold limits implied in ISO2631.1. In particular, the upper health guidance caution zone values implied in ISO2631.1 are more protective than the upper ELV values 'above which workers must not be exposed". We recommend that ISO2631.1/AS2760.1 be used for measurement and evaluation of whole-body vibration exposures in Australia.

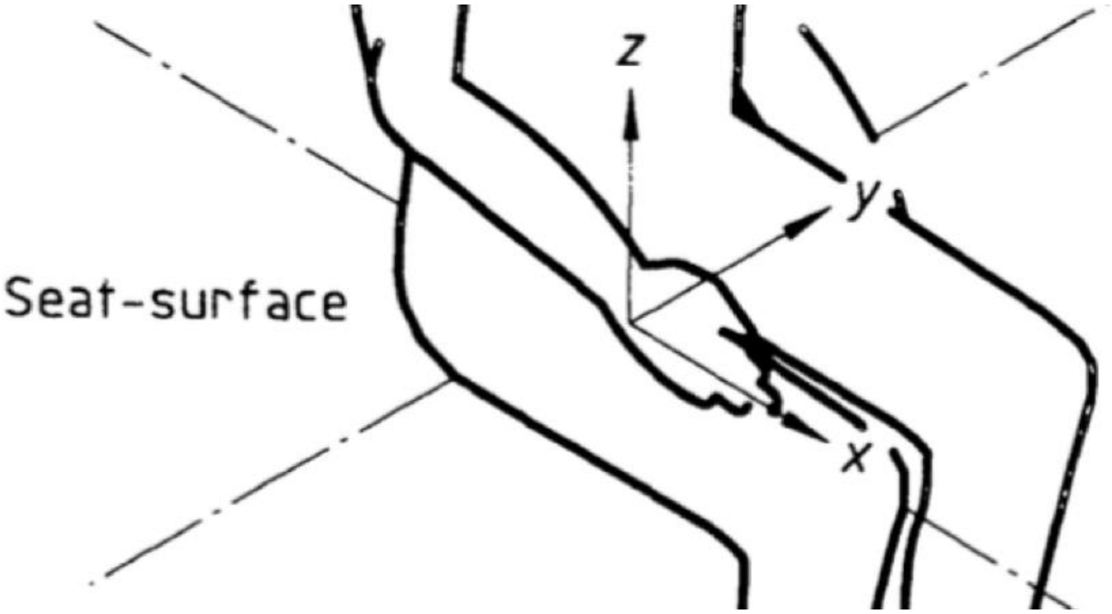
21.9 How is the hazard measured/evaluated in the workplace?

21.9.1 Current method and its limitations

ISO2631.1 provides guidance regarding the measurement and evaluation of the health effects of whole-body vibration. Obtaining the measurements typically involves the use of a seat-pad mounted accelerometer connected by relatively fragile cable to an analysis module. As well as the equipment being expensive, the interfaces are complex and considerable training is required to enable data to be collected and interpreted. Therefore, workplaces such as mines undertake measurement of whole-body vibration only infrequently and there have been only limited assessments of whole-body vibration in the mining industry. These ad hoc measurements are unlikely to reliably capture the varying degrees of whole-body vibration exposure experienced by equipment operators, or provide the information required to effectively manage operator whole-body vibration exposures. Consequently, there is little evidence to guide implementation of appropriate control management strategies by mine management.

ISO2631.1 (ISO, 1997; 2010) provides procedures for the collection and evaluation of whole-body vibration measurements. The standard identifies acceleration as the primary quantity by which to measure vibration and provides instruction as to the direction, location, and duration of measurements. The response of the human body to vibration is a function of frequency, and the measured vibration data are "weighted" to accentuate the frequencies where humans are more sensitive. Weightings are defined for Z direction and for the X and Y directions as defined by ISO 2631.1 (figure below). The Z direction measurement is most frequently associated with jolts and jars from equipment operation.

Figure 29: X, Y & Z components of whole-body vibration in a seated posture defined by ISO2631.1.



21.9.2 Historical measurement (Australia)

McPhee et al [11-12] reported a two-year study conducted at four open cut coal mines and four underground coal mines in Australia. Commissioned by the Joint Coal Board Health and WorkSafe Queensland in 2001, this study was the first, and until recently only major study in Australia to investigate whole-body vibration exposures of drivers and passengers in mining vehicles. All vehicle rides for underground equipment (except for rail personnel carriers, locos, dolly cars and the driver of a front steering 4WD) reached the health guidance caution zone in less than an 8-hour exposure period. The worst rides in some of the front steer vehicles reached the health guidance caution zone in 12 minutes. Subsequently, McPhee et. al. synthesised the findings of these studies into an industry handbook called Bad Vibrations [12], which aimed to assist those in mining and other heavy industries to identify and manage the risked associated with whole-body vibration.

21.9.3 Emerging technology/research

The development of an iOS application (WBV) allows the accelerometer within the inexpensive and commercially readily available iPod Touch to record and analyse long duration whole-body vibration exposures [16-19]. This application has created an opportunity for the information required for an effective whole-body vibration management plan to be obtained more easily. The iOS application installed on a fifth-generation iPod Touch was shown to provide a 95% confidence of +/− 0.077 m/s^2 r.m.s. constant error for the vertical direction. A detailed description of the WBV app and peer reviewed research papers validating the accuracy of the application is contained in the references provided. (http://burgesslimerick.com/site/WBV/WBVpod/Index.html) [12].

The WBV application has made it possible to use consumer hardware to gather long duration whole-body vibration exposure estimates across many pieces of equipment simultaneously. The relatively low cost of the iPod Touch hardware, and the accuracy and simplicity of the WBV application, provide the opportunity for collection of long duration whole-body vibration exposure data during normal mine site operations at both surface and underground coal mines. It also provides an opportunity for data collection by site-based workplace safety and health staff as part of a systematic whole-body vibration risk management program.

A currently funded Australian Coal Association Research Program (ACARP) has enabled real time continuous monitoring of floor and seat accelerometers installed in earth-moving equipment at a Queensland surface coal mine. A miniature accelerometer has been located within truck seats and connected by a cable to an external recording and transmitting device incorporating a GPS module and remote accelerometer located outside the seat. A second accelerometer has been installed under the seat and connected to the module. Multiple units have been installed and simultaneous recordings from both accelerometers allow for a more detailed examination of the attenuation capabilities of the vehicle seats to be achieved. The data enables evidence-based decisions to be made regarding control measures to manage whole-body vibration exposures and allows the identification of events with acute injury potential such as excavator strikes. The implementation of this technology demonstrates the ability to undertake real-time monitoring of operator exposures to whole-body vibration and provides the opportunity for evidence-based decisions regarding effective control measure implementation. Further details of this project are available on the ACARP website (www.acarp.com.au)]13].

21.10 Summary of health monitoring data currently available to RSHQ

21.10.1 Data provided

- Lost time injury data
- Accepted Workers' Compensation claims,
- Health Risk Assessments preformed at individual sites

21.10.2 LTI data

During the period 2011- 2020 there were ninety-six (96) reported lost time injuries attributed to vibration. These included:

- 57 back
- 11 neck
- 21 upper limb (including 9 wrist/Carpal Tunnel Syndrome)
- 8 other parts of the body (hip, head, abdomen)

Narrative quality was inconsistent within the data provided, however most reported injuries were sustained either whilst working in the pit area or travelling in a vehicle.

21.10.3 Workers' compensation data

The accepted workers' compensation claims data for 2016/2017 to the incomplete year 2020/2021 includes:

- 1 claim directly attributed to exposure to mechanical vibration (opencut mining sector)

The cumulative nature of the effects of whole-body vibration on the human body and the varied sources of exposure may mean that a number of injuries (whether compensated or not) did not include exposure to whole body vibration as a mechanism of injury descriptor.

Additional claims that may be related to whole-body vibration exposure were categorised as:

- Muscular stress with no object handled
- Multiple mechanisms of injury
- Hitting stationary objects

21.10.4 Health Risk Assessments

The Health Risk Assessments provided included reviews completed for specific sites, including coal mines (3 reports), metalliferous mines (1 report), and petroleum and gas drill rig sites (6 reports). Vibration was briefly listed as an occupational health hazard in most of the HRAs, however guidance in managing the hazard is minimal.

The *Queensland Hazardous Manual Tasks Code of Practice* (2021) provides some guidance for assessment of whole-body vibration exposure including a risk assessment sheet. However, without background understanding of the workplace factors leading to whole-body vibration exposures, consideration of the cumulative nature of the exposures, and a simple and effective measurement method it is difficult to obtain accurate data on exposure levels within the industry.

The current whole-body vibration exposure data held by RSHQ is minimal, consisting of a small amount of qualitative data but no quantitative data. There are some LTI reports and workers' compensation claims data, however there is little qualitative information to assist with evaluation of the data provided. More data is needed to be able to evaluate the magnitude of and variability of the causes of whole-body vibration exposures in the Queensland mining, quarrying and petroleum and gas sector. Without more data, we cannot understand the full extent of risk exposure and subsequent exposure outcomes in the Queensland resources sector.

21.10.5 How could data collection and management be improved?

Recent research [13-22] indicates operators of mobile earth moving equipment at both surface and underground Australian coal mines are exposed to whole-body vibration exposures often within and above the ISO 2631.1 recommended health guidance caution zone (HGCZ). The findings indicate whole-body vibration exposure is widespread across industry, is infrequently measured and poorly managed. Monitoring and managing whole-body vibration exposures is challenging.

Adopting the NSW regulator approach of targeted assessment programs where an in-depth review/measurement of one key health issue is undertaken across multiple mine sites to gauge the significance of the issue, with the findings reported back to industry may be a positive industry initiative for RSHQ to consider. This approach improves data collection effectiveness and quality and enables industry dissemination of information to help inform the strategies required to manage the identified health risk.

The availability of low cost, accurate and simple to use whole-body vibration measurement tools provide the opportunity for collection of long duration whole-body vibration exposure data during normal site operations by site-based workplace safety and health staff. Subsequently, this data could inform the implementation of a systematic whole-body vibration risk management program.

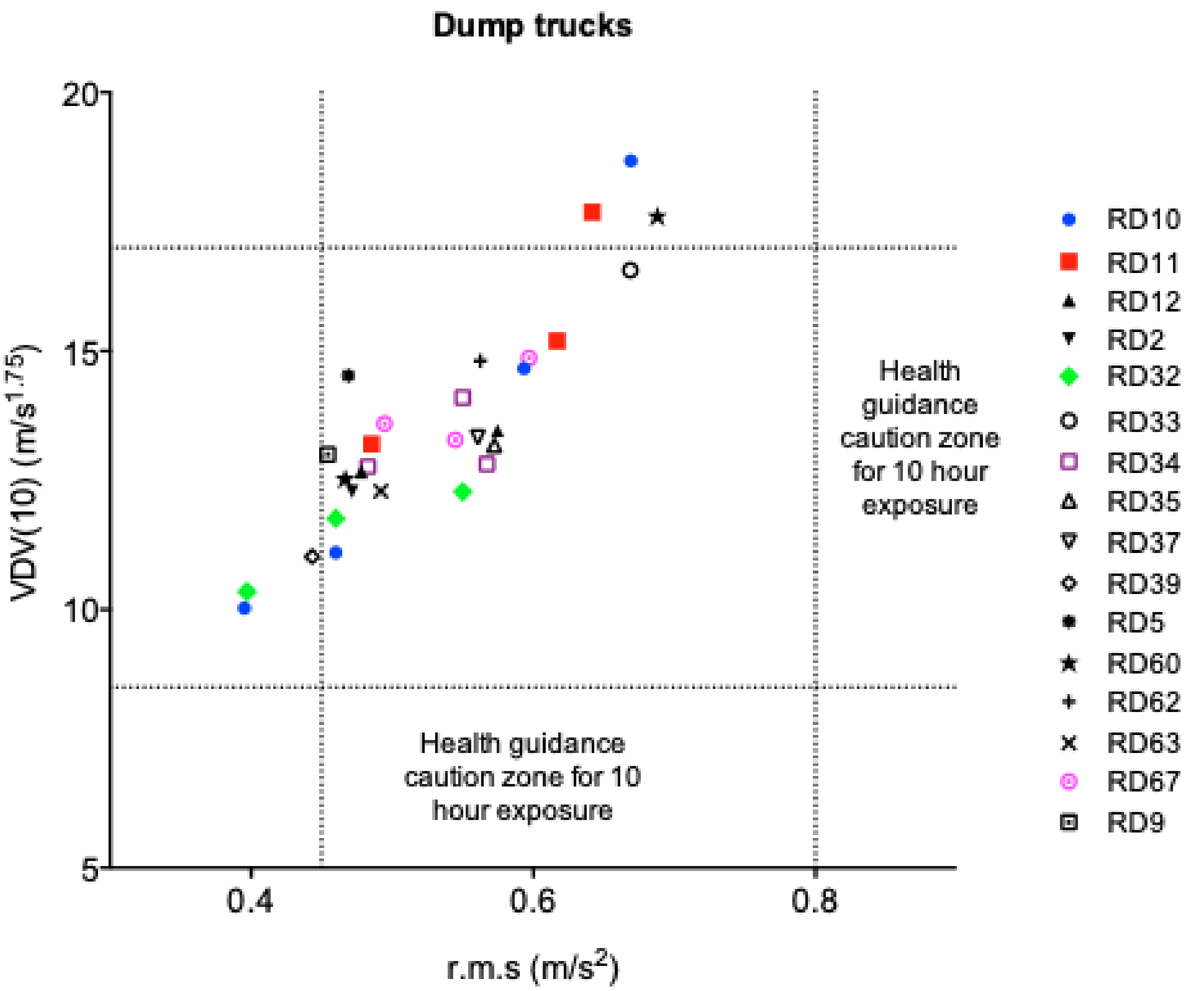
21.11 What other exposure data is available/in peer reviewed literature?

21.11.1 Peer reviewed literature

Between 2013-2019 Lynas & Burgess-Limerick [13-18] obtained measurements across a range of mobile mining equipment deployed at Australian surface and underground coal mines during normal operations using an iOS application (WBV) installed on multiple iPod touch devices. This data forms the most comprehensive database available of whole- body vibration exposures in the Australian mining sector.

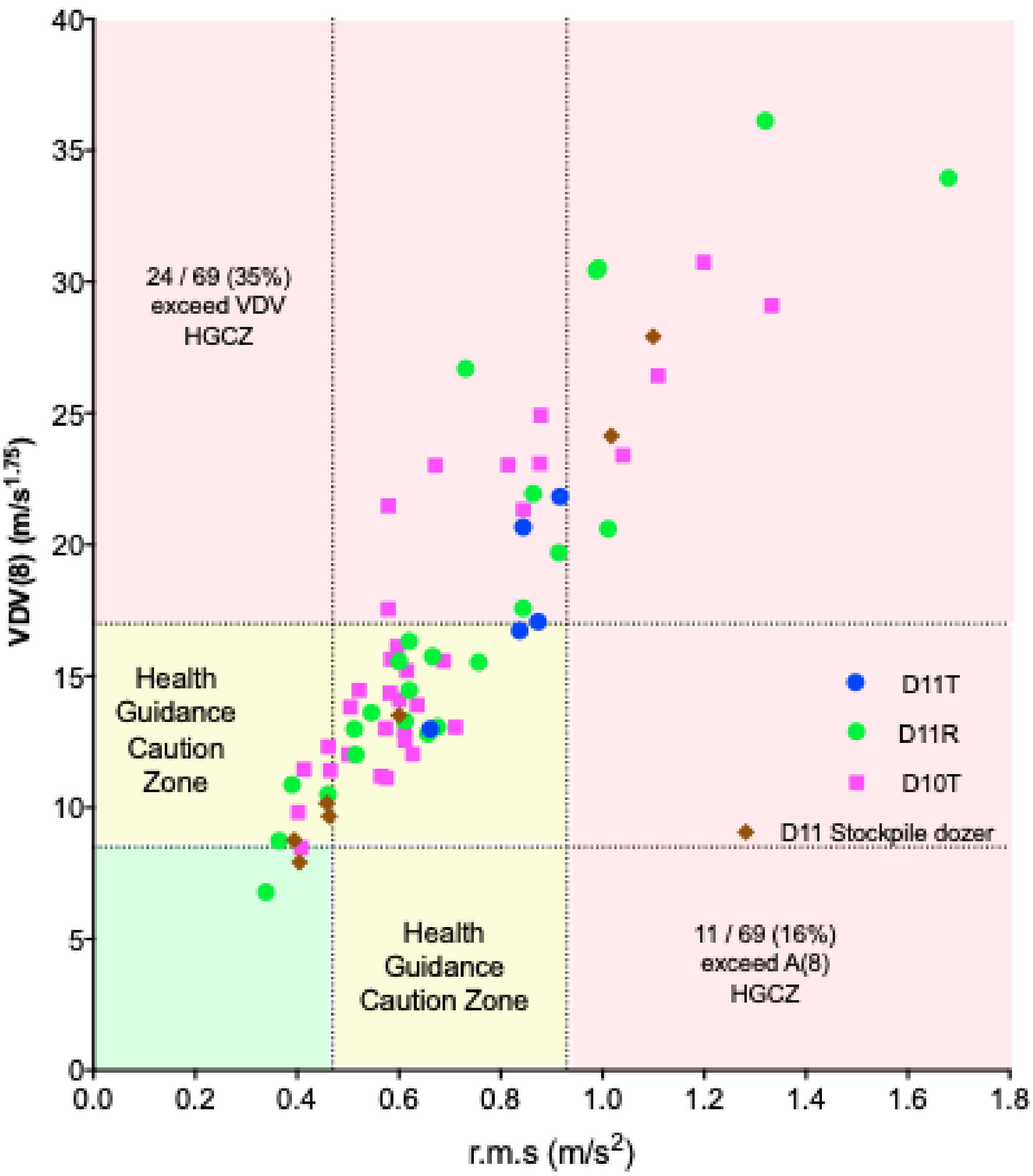
172 long duration measurements were obtained from equipment in use at three surface mines, and 265 long duration measurements from equipment in use at three underground mines. The results of the 172 long duration measurements obtained confirmed the variability seen in measurements was consistent across open cut mining equipment, and not site specific. Dozer measurements frequently exceeded the ISO2631.1 health guidance caution zone. In addition, 274 short duration measurements were obtained to determine the effect of speed and roadway maintenance on whole-body vibration exposures in underground mining operations. A number of potential control measures were implemented and evaluated. The figures below graphically illustrate the severity of whole-body vibration exposures.

Table 49: VDV (10) vs r.m.s values for each of 29 long duration vertical whole-body vibration measurements taken from dump trucks during normal operations at a surface coal mine.



As we can see from this table, almost all of these measurements show exposures within or above the health guidance caution zone. According to ISO 2631.1, for exposures within the health guidance caution zone, "caution with respect to potential health risks is indicated"; and for amplitudes greater than the health guidance caution zone, it is suggested that "health risks are likely".

Table 50: VDV (8) vs RMS values for each of 69 long duration vertical whole-body vibration measurements taken from dozers during normal operations by size of dozer (D11, D10R, D10T, D11 Stockpile dozer). Measurement duration ranged from 140 to 660 minutes, median measurement duration = 440 minutes.



This table shows similar measurements to the one above for dump trucks. Most measurements are within or above the HGCZ.-According to ISO 2631.1, for exposures within the health guidance caution zone, "caution with respect to potential health risks is indicated"; and for amplitudes greater than the health guidance caution zone, it is suggested that "health risks are likely".

Table 51 and Table 52 below for personnel vehicles, and shuttle cars, also show most measures within or above the HGCZ, indicating that "health risks are likely".

Table 51: Comparison vertical whole-body vibration measurements taken from personnel and supply vehicles at one underground coal mine site. The data are expressed as VDV(8) and r.m.s. with respect to ISO2632.1 health guidance caution zone (HGCZ) for an 8-hour daily exposure.

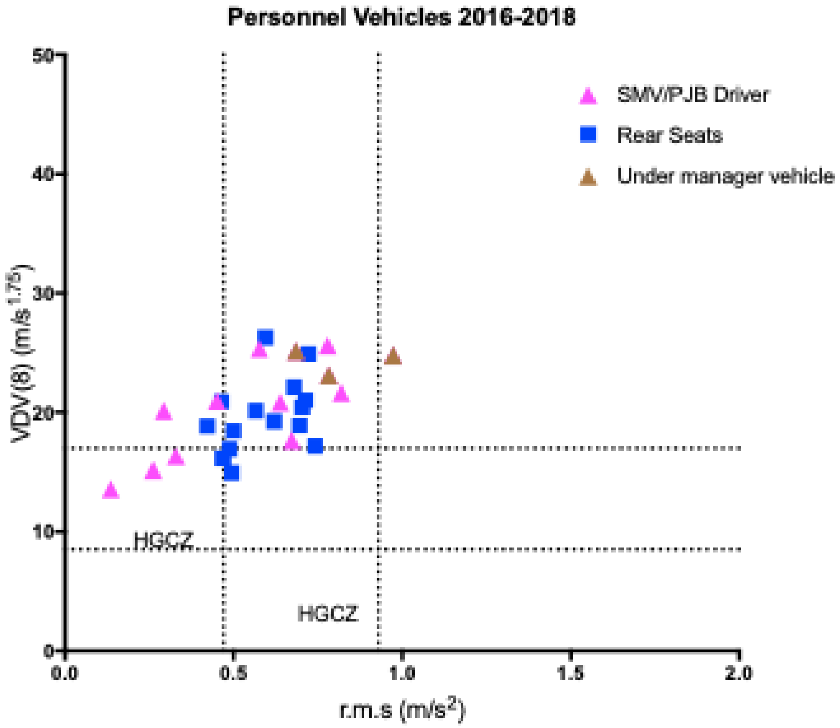
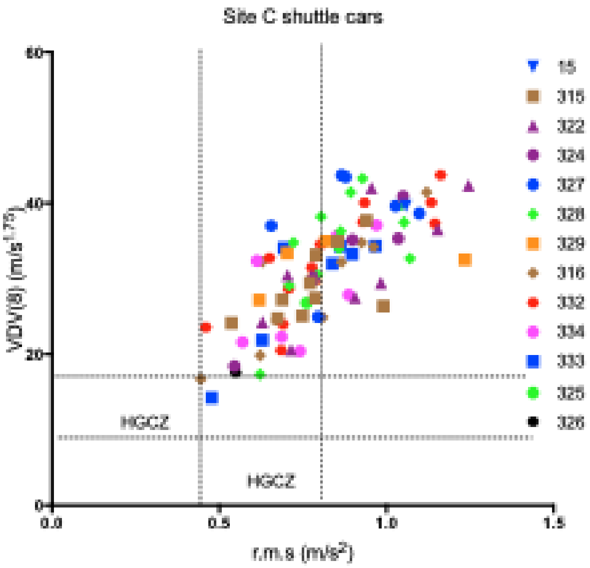


Table 52: Measurements obtained from individual shuttle cars at an underground coal mine. The data are expressed as VDV(8) and r.m.s. with respect to ISO2632.1 health guidance caution zone (HGCZ) for an 8-hour daily exposure.



Baxter [23] further investigated whole-body vibration exposures at a surface coal mine in NSW. This study involved a two-year data collection period to record whole-body vibration data, which was also matched to corresponding video of dozer operation. A total of 366 hours of whole-body vibration data and corresponding video footage was analysed. Descriptive statistics, as well as one-way and two-way Analysis of Variance were utilised. Dozer operation in blocky ground conditions consistently produced higher whole-body vibration exposures, while task characteristics were not as predictive.

21.11.2 International studies

A number of international studies have investigated whole-body vibration exposures in surface and underground mines. For example, studies undertaken at mines in Ontario Canada [24-26] have included measurement of whole-body vibration during the operation of small and large haulage capacity LHDs while performing three tasks (loaded travel, unloaded travel and mucking) over similar underground terrain at eight mine sites. The results indicated that driving a LHD with an unloaded bucket resulted in significantly higher levels of vibration exposure than driving with a loaded bucket, and that health risks were likely to develop. Operators of smaller LHD vehicles were exposed to vibration levels above the ISO2631.1 health guidance caution zone, while some operators of larger LHD vehicles experienced whole-body vibration levels that placed them within the health guidance caution zone and some operators experienced levels that placed them above the health guidance caution zone.

Brunstrom [27] obtained measurements from six dozers in operation at during surface operation at mines in mines in Finland, Norway, and Sweden. The measurement duration ranged from 35 to 150 minutes. The vertical direction acceleration amplitudes measured ranged from 0.28 to 1.04 m/s^2 (Mean = 0.7 m/s^2, SD 0.3 m/s^2), meaning most measurements lay within the ISO2631.1 health guidance caution zone for an 8-hour exposure.

Marin et al [28] reported whole-shift vibration measurements taken from a range of equipment at a Columbian surface coal mine. A total of 846 hours of whole-body vibration measurements were recorded from 38 vehicles. Results indicated differences measured in whole-body vibration exposure parameters reduced acceptable vehicle operation times by one-half to two-thirds relative to A (8) exposures, suggesting the time to reach daily vibration action limits with most mining vehicles would be limited to less than 8 hours a day.

21.11.3 Non resources sector studies

A number of international studies have considered the effects of operator exposure to whole-body vibration during operation of large equipment in industries outside the resource sector, including agricultural and transport industries. For example, a meta-analysis which focused specifically on heavy vehicle equipment operators indicated operators were at more than twice the risk of developing low back pain in comparison with non-heavy vehicle operators.

Another study evaluated low back pain and whole-body vibration exposure in tractor and bus drivers. This study was the first to suggest that the duration of whole-body vibration exposure was more consistently related to low back pain than the magnitude of the vibration suggesting a possible dose relationship. Results increased risk for degenerative changes of the spinal system in crane operators, tractor drivers and transportation industry drivers.

In a study which evaluated whole-body vibration on equipment used in the construction industry, measurements from 14 different types of heavy equipment. Whole-body vibration exposure was found to be elevated for 10 of the 14 types of equipment tested, with scrapers having the greatest whole-body vibration levels. Health levels were exceeded on wheel loaders, skid steer vehicles, back hoes, bulldozers, and off-road load haul-dump trucks.

A number of authors have investigated whole-body vibration in agricultural equipment. A European study quantified whole-body vibration exposure in a range of modern state-of-the-art agricultural tractors under controlled "in-field" and "on farm" operating conditions. Approximately 9% of "on farm" operations exceeded the Exposure Limit Value (ELV) for 8 hours operation, increasing to 27% during longer working days. The researchers referenced to the *European Physical Directive: 2002* in the study in relation to potential consequences of operator whole-body vibration limitations. Concerns were raised for operator health if working hours increased to 15 hours or more per day. A USA study investigated whole-body vibration exposures of farming equipment operators finding smaller vehicles such as tractor mowers and skid-steer loaders provided the roughest operator rides.

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Appendices

Appendix A (Appendix 4 of the NOSHC, 1990 guideline on Welding: Fumes and Gases, AGPS, Canberra)

Metal fumes

Lead

Potential lead exposure occurs during welding and cutting of any metal coated with lead or lead based paint. Lead poisoning is rare in welders, but may occur in persons employed in operations such as cutting lead-painted steel in ship breaking and bridge demolition. Occupational lead poisoning, which in welders results from exposure to lead oxide fume, may affect the blood, gastrointestinal tract, and nervous system.

Cadmium

Cadmium may be present as a coating in certain materials being welded. Cadmium oxide fume on inhalation may cause acute irritation of the respiratory passages, bronchitis, chemical pneumonia, or excessive fluid in the lung tissues (pulmonary oedema). There may be a latent period of several hours between exposure and onset of symptoms. The effects of overexposure to cadmium fumes may resemble metal fume fever initially. A single exposure to a very high concentration of cadmium oxide fume may be fatal. Chronic cadmium poisoning results in injury to lungs and kidneys.

Manganese

Potential exposure to manganese occurs whenever this metal is used in electrode cores and coatings or in electrode wire. Acute poisoning from oxides of manganese is very rare in welders, although respiratory tract irritation from the fume may occur. Exposure to fume from welding on manganese steel may give rise to acute inflammation of the lungs. Metal fume fever is also a possibility after exposure to manganese fume. Chronic manganese poisoning, characterised by a severe disorder of the nervous system, has been reported in welders working in confined spaces on high-manganese steels.

Zinc

Zinc may be present as a surface coating on steel products, that is, galvanised steel.

Exposure to freshly formed zinc oxide fume may produce a brief acute self-limiting illness known as metal fume fever, zinc chills or brass founders' ague. The symptoms, which resemble those of an acute attack of influenza, usually occur several hours after exposure to fume and usually with complete recovery within about 24 to 48 hours. Freshly formed oxide fume from several other metals has also been reported to cause metal fume fever. Leucocytosis, a transient increase in white blood cell counts, is reported to be a common finding in metal fume fever but is not known to be common among welders.

Iron

Most welding involves ferrous materials. The most abundant constituent of ferrous alloy welding fume is iron oxide. Long, continued exposure to such welding fume may lead to the deposition of iron oxide particles in the lungs. When present in sufficient quantities, the deposition is demonstrable on chest X-ray films as numerous fine discrete opacities (nodulation and stripping) resembling silicosis. The technical name for this is siderosis and it is a benign form of pneumoconiosis. Siderosis tends to clear up when the exposure to metallic particles stops.

Molybdenum

Molybdenum is found in some steel alloys. Molybdenum fumes may produce bronchial irritation and moderate fatty changes in the liver and kidneys.

Cobalt

Cobalt is a component in some high-strength, high-temperature alloys. Inhalation of cobalt fumes can cause shortness of breath, coughing and pneumonitis. Hypersensitivity appears to be involved because lung changes occur at low incidence and are varied in intensity and time of onset. In most cases, the symptoms disappear after exposure ends.

Vanadium

Vanadium may be present in some filler wires and special alloy steels. Exposure to oxide fume, especially pentoxide (V2O5), gives rise to severe irritation of the eyes, severe throat, and respiratory tract irritation, and may also cause chemical pneumonia.

Nickel

Nickel is a potentially carcinogenic metal found in fumes from the welding of nickel-plated mild steel, and stainless steel and high-strength low-alloy steel electrodes. Nickel oxide has been found to be carcinogenic in laboratory animals. There is, however, very little direct information on the health effects of nickel-bearing welding fume on welders. Irritation of the respiratory tract has occurred in stainless steel welders.

Chromium

Chromium may be present as a coating on the workpiece, and mainly in stainless steel, hardfacing and chrome-alloy electrodes. Chromium is normally not present in any significant amount in aluminium alloys. Chromate, which may be generated in stainless steel welding fumes or in fumes from hardfacing and chrome-alloy electrodes, is an irritant to the mucosal tissue in the respiratory tract. Exposure to fume containing high concentrations of water-soluble chromium (VI) during the welding of stainless steel in confined spaces has been reported to result in both acute and chronic chrome intoxication, dermatitis, and asthma.

Epidemiological studies and animal tests have confirmed certain chromium (VI) compounds as occupational carcinogens. These health risks were determined from non-welding occupations.

GMAW stainless steel welders are usually likely to be exposed to much smaller concentrations of chromium (VI) than MMAW stainless steel welders. A considerable amount of stainless-steel welding is carried out nowadays using GMAW and GTAW methods.

Chromium (III) compounds are generally believed to be biologically inert. Welding fumes may contain Cr_2O_3 (a chromium (III) compound), or double oxides, such as FeO Cr_2O_3, or both.

Silica and silicates

The silica and silicates formed in welding fumes are amorphous, that is, not crystalline, and are generally believed not to be harmful.

Fluorides

Welders may be exposed to fluoride dust, fume, and vapours from certain MMAW, FCAW and GMAW operations and SAW fluxes. Fluoride fumes may produce irritation of the eyes, throat, respiratory tract, and skin. Chronic fluorosis is a syndrome characterised by an increased density of bones and ligaments due to fluoride deposition. However, no corroborating data are available which identify a relationship between exposure to fluoride-containing welding fumes and disorders of bones or ligaments.

Other metals

Welding may produce fume from other metals, including aluminium, copper, magnesium, tin, titanium, and tungsten. Within the confines of the current information available, no serious health disorders in welders are known to occur from exposure to fume from these metals but, under certain conditions, copper, aluminium and magnesium may give rise to metal fume fever and others to irritation of the respiratory tract.

Beryllium is a volatile and toxic component that may be present in many copper alloys being welded, that is, in the workpiece itself. Beryllium oxide fume is very toxic to the respiratory tract, lungs, and skin, and is quick-acting. Beryllium is a suspect human carcinogen. Note that beryllium may also be present in some aluminium or magnesium brazing alloys.

Gases

Oxides of nitrogen

The oxides of nitrogen (nitric oxide and nitrogen dioxide) are frequently formed by the direct combination of oxygen and nitrogen in the air surrounding the arc or flame, as a result of heat from the electric arc or gas torch (oxidising flames). In outdoor or open shop welding, hazardous abnormal concentrations are unlikely, except perhaps for short periods. In confined spaces, hazardous concentrations of nitrogen oxides may rapidly build up in welding operations. High concentrations of nitrogen oxides have also been found during gas tungsten-arc cutting of stainless steel.

Exposure to oxides of nitrogen may not always produce immediate effects but may result in fatal excessive fluid in the lung tissues (pulmonary oedema) some hours after the exposure stops.

Ozone

Ozone is formed only in small amounts in MMAW and in gas welding. It is, however, produced in significant amounts in GMAW when welding with argon, especially when high amperages are used. High ozone concentrations are especially a problem when welding on reflective surfaces, such as aluminium and its alloys and stainless steel, and with high-energy processes such as plasma arc welding.

Ozone is formed a short distance away from the arc. The persistence of ozone under certain conditions may be explained as an inverse function of the amount of fume produced. The greater the mass of fume (particulate), the less the penetration by ultraviolet radiation and thus the less ozone produced by the ultraviolet radiation acting on oxygen. Ozone also reabsorbs ultraviolet radiation of wavelengths of 200 to 290 nm and can spontaneously decompose back to oxygen.

Harmful levels of ozone may be found in welding in confined spaces. The gas is very irritant to the upper respiratory tract and lungs and its effects may be delayed. Ozone can react explosively with combustible materials.

Carbon monoxide

Carbon monoxide is derived from carbon dioxide-shielding atmospheres by reduction of shielding gas, and to a much lesser extent in all welding of steel by partial oxidation of carbon in the consumables. Carbon monoxide will also be produced in gas welding when combustion of acetylene is incomplete, as with a reducing flame. Carbon monoxide levels may build up in confined spaces and poorly ventilated spaces. Overexposure may cause drowsiness, headache, and nausea. If carbon monoxide exposure is sufficiently severe, unconsciousness may occur.

Carbon dioxide

Carbon dioxide at high concentrations can act as an asphyxiant. It is therefore necessary in GMAW in confined spaces to maintain adequate air and oxygen to avoid asphyxiation of the welder. Note that high oxygen concentrations should also be avoided since they constitute a fire hazard.

Phosgene

The toxic gas phosgene, also known as carbonyl chloride, is not a normal component of welding gases, but is formed by the oxidation of chlorinated hydrocarbons (for example, trichloroethylene, trichloroethane and perchloroethylene), such as when welding is carried out in the presence of solvent vapours escaping from a nearby degreasing tank or when solvent is left behind after degreasing. Exposure to phosgene produces, after a latent period of several hours, irritation of the respiratory tract or perhaps serious lung damage.

Phosgene formation is promoted by ultraviolet radiation, hot metal surfaces, flame and cigarette smoking. The gas-shielded arc welding processes (GMAW and GTAW) and plasma processes provide greater ultraviolet light intensity than the flux-shielded arc welding processes (MMAW, SAW, FCAW). Note also that heat and ultraviolet radiation from the welding arc may react with solvent vapour to produce irritant gases such as acetylchloride and acetylchloride derivatives such as dichloroacetylchloride.

Phosphine

Phosphine is generated when steel coated with a rust proofing compound is welded. High

concentrations of phosphine gas are irritating to the eyes, nose and skin. There may also be serious effects on the lungs and other organs.

Insufficient oxygen

In GMAW, the presence of inert gases (argon, helium) in confined work environments may reduce the oxygen content of the atmosphere to dangerous levels, with the threat of asphyxiation. See also the section on carbon dioxide in this appendix.

Pyrolytic products of resins used in primers/paints

The main products of thermal decomposition of resins used in primers and paints are carbon monoxide and carbon dioxide. Specific toxic or irritant chemicals given off from the resins used in priming materials include such hazardous substances as phenol, formaldehyde, acrolein, isocyanates and hydrogen cyanide. Usually, a very complex mixture of organic gases is formed.

Appendix B Blood lead analysis

Table 53: Icon Set Meanings for Blood Lead Levels for Males and Females—using Safe Work Australia BEI

	Blood Lead (ug/dL)	
	Male	Female
	<20	<5
	>20<30	>5<10
	>30	>10

Table 54: Male Blood Lead Levels by Age Group

Males by Age Group	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
≤20	1253	14.965	4.018	45.2	41.182	6.424	15.264	13.471	1.617	15.117	15.491
21-30	11950	15.089	0.001	44.195	44.194	6.617	15.188	13.513	1.645	15.296	15.422
31-40	8291	13.164	0.001	36.16	36.159	6.203	13.276	11.712	1.654	13.292	13.425
41-50	6586	13.003	0.642	37.692	37.05	6.280	13.130	11.529	1.649	13.064	13.210
51-60	4917	13.317	4.97	42.186	37.216	6.536	13.470	11.735	1.670	13.384	13.563
61-70	1124	12.898	4.97	41.213	36.243	6.689	13.227	11.313	1.672	12.910	13.276
71-75	21	7.574	5.022	15.067	10.045	2.856	8.649	7.150	1.398	7.542	8.675

Table 55: Female Blood Lead Levels by Age Group

Females by Age Group	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
≤20	42	6.010	5.022	12.053	7.031	1.588	6.422	5.859	1.238	5.991	6.348
21-30	552	7.650	4.97	24.106	19.136	3.555	7.899	7.098	1.429	7.564	7.768
31-40	405	7.212	4.97	26.115	21.145	3.103	7.467	6.774	1.388	7.146	7.352
41-50	350	7.138	5.022	19.084	14.062	2.601	7.367	6.777	1.358	7.100	7.304
51-60	211	6.738	5	15.067	10.067	1.682	6.930	6.553	1.261	6.731	6.917
61-70	36	6.586	5.022	13.047	8.025	1.938	7.132	6.356	1.298	6.569	7.101
71-75	12	7.090	6.027	8.9	2.873	0.915	7.565	7.038	1.134	7.089	7.587

Table 56: Male Blood Lead Levels by Quarter

Males by Quarter	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2017-Q3	1197	13.864	4.97	37.164	32.194	6.849	14.189	12.152	1.696	13.969	14.364
2017-Q4	2511	14.391	4.97	42.186	37.216	6.932	14.619	12.670	1.685	14.517	14.794
2018-Q1	1263	14.196	5.022	37.692	32.67	6.690	14.506	12.579	1.661	14.307	14.683
2018-Q2	2187	13.276	0.001	33.146	33.145	6.101	13.490	11.802	1.703	13.599	13.885
2018-Q3	2268	13.542	0.001	33.146	33.145	6.176	13.756	12.021	1.716	13.906	14.197
2018-Q4	3411	14.690	0.518	38.169	37.651	6.955	14.886	12.973	1.681	14.847	15.088
2019-Q1	1948	14.308	5	45.2	40.2	7.027	14.570	12.552	1.695	14.427	14.745
2019-Q2	2895	13.481	5	39.556	34.556	6.488	13.679	11.946	1.652	13.550	13.780
2019-Q3	2821	13.798	4.97	41.213	36.243	6.395	13.996	12.285	1.643	13.896	14.133
2019-Q4	4489	14.182	3.013	42.186	39.173	6.638	14.345	12.592	1.654	14.292	14.487
2020-Q1	2309	13.601	4.97	37.485	32.515	6.192	13.813	12.180	1.620	13.681	13.930
2020-Q2	3401	13.720	4.97	44.195	39.225	6.169	13.894	12.301	1.618	13.810	14.017
2020-Q3	995	13.174	4.97	32.142	27.172	5.873	13.480	11.840	1.608	13.251	13.615
2020-Q4	2447	13.402	4.97	35.155	30.185	6.061	13.604	12.029	1.610	13.472	13.707

Table 57: Female Blood Lead Levels by Quarter

Females by Quarter	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2017-Q3	66	6.417	5.022	10.044	5.022	1.365	6.698	6.286	1.223	6.413	6.694
2017-Q4	131	7.273	5.022	20.089	15.067	2.968	7.703	6.864	1.372	7.213	7.572
2018-Q1	65	7.186	5.022	15.067	10.045	2.683	7.741	6.780	1.391	7.154	7.699
2018-Q2	83	6.902	5.022	15.067	10.045	2.070	7.280	6.651	1.302	6.883	7.240
2018-Q3	81	7.452	5.022	19.084	14.062	3.191	8.042	6.964	1.414	7.389	7.916
2018-Q4	173	7.611	4.97	26.115	21.145	3.726	8.080	7.034	1.441	7.516	7.895
2019-Q1	116	6.820	4.97	21.093	16.123	2.547	7.212	6.498	1.336	6.774	7.100
2019-Q2	128	7.406	5	24.106	19.106	3.480	7.916	6.856	1.441	7.325	7.759
2019-Q3	137	7.836	5.022	21.093	16.071	3.484	8.329	7.265	1.447	7.774	8.224
2019-Q4	221	7.013	4.97	22.098	17.128	2.625	7.304	6.685	1.332	6.965	7.202
2020-Q1	107	6.914	4.97	20.089	15.119	2.537	7.321	6.585	1.342	6.873	7.224
2020-Q2	151	7.244	4.97	19.084	14.114	3.031	7.653	6.838	1.366	7.176	7.502
2020-Q3	38	7.329	5.022	21.093	16.071	3.047	8.163	6.942	1.353	7.259	7.935
2020-Q4	111	7.452	4.97	20.089	15.119	2.954	7.917	7.038	1.375	7.400	7.805

Table 58: Males with Highest Average Blood Lead Levels

Males w/ highest average exposure	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
1069786	1	36.160	36.16	36.16	0	-	-	36.160	-	-	-
159441	1	34.151	34.151	34.151	0	-	-	34.151	-	-	-
5496502	10	28.621	19.084	35.155	16.071	4.694	31.342	28.242	1.193	28.642	31.946
5173185	7	28.530	11.049	42.186	31.137	10.506	36.246	26.441	1.575	28.857	45.300
1894907	1	28.166	28.166	28.166	0	-	-	28.166	-	-	-
6335579	1	28.124	28.124	28.124	0	-	-	28.124	-	-	-
1695063	13	28.047	14.062	42.186	28.124	9.109	32.550	26.644	1.404	28.093	34.027
72734	9	28.015	22.098	36.16	14.062	4.806	30.994	27.664	1.182	28.008	31.268
5531099	11	27.639	13.047	41.213	28.166	9.092	32.607	26.214	1.419	27.705	34.615
481335	4	27.622	22.098	31.138	9.04	4.059	32.399	27.384	1.167	27.630	33.976
5639235	2	27.622	26.115	29.129	3.014	2.131	37.137	27.581	1.080	27.622	-
1826340	40	27.588	21.093	35.155	14.062	2.903	28.361	27.435	1.113	27.590	28.404
5641843	1	27.120	27.12	27.12	0	-	-	27.120	-	-	-
3549157	39	26.984	18.08	31.138	13.058	2.328	27.612	26.875	1.098	26.990	27.694
3537106	45	26.830	23.102	36.16	13.058	2.620	27.486	26.712	1.098	26.827	27.473
5596244	1	26.700	26.7	26.7	0	-	-	26.700	-	-	-
5635784	2	26.618	22.098	31.138	9.04	6.392	55.156	26.231	1.274	26.618	-
5635646	12	26.534	23.102	30.133	7.031	2.118	27.632	26.455	1.084	26.534	27.694
3632820	2	26.380	15.067	37.692	22.625	15.998	97.804	23.831	1.912	26.379	-
6248485	4	26.367	14.062	35.155	21.093	8.885	36.821	24.998	1.490	26.517	56.510

Table 59: Females with Highest Average Blood Lead Levels

Females w/ highest average exposure	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2546970	21	18.702	9.04	22.098	13.058	2.885	19.787	18.416	1.215	18.752	20.254
1083556	13	18.621	8.036	26.115	18.079	5.099	21.141	17.861	1.374	18.709	22.337
627281	12	17.578	13.058	24.106	11.048	3.248	19.261	17.308	1.201	17.576	19.442
5791615	3	15.325	12.84	18.432	5.592	2.847	20.125	15.154	1.200	15.323	-
1854810	1	15.067	15.067	15.067	0	-	-	15.067	-	-	-
5636874	9	14.397	8.036	20.089	12.053	4.172	16.983	13.831	1.359	14.419	17.961
3575663	16	13.092	7.031	19.084	12.053	3.240	14.512	12.706	1.293	13.104	14.806
5338921	7	11.849	9.04	15.067	6.027	1.836	13.198	11.728	1.168	11.850	13.387
4782323	1	11.598	11.598	11.598	0	-	-	11.598	-	-	-
3553335	7	11.049	9.04	14.062	5.022	1.923	12.461	10.910	1.186	11.047	12.647
903235	5	11.049	5.022	15.067	10.045	3.825	14.696	10.365	1.538	11.153	20.467
783865	3	11.049	10.044	12.053	2.009	1.005	12.742	11.018	1.095	11.049	-
637817	1	10.976	10.976	10.976	0	-	-	10.976	-	-	-
6215875	1	10.769	10.769	10.769	0	-	-	10.769	-	-	-
5616912	13	10.417	5.022	15.067	10.045	3.066	11.933	9.964	1.378	10.446	12.494
325208	5	10.245	7.031	15.067	8.036	3.286	13.378	9.851	1.363	10.234	14.958
1777282	6	10.217	5.385	13.462	8.077	3.009	12.692	9.774	1.410	10.264	14.690
4457120	2	10.148	9.941	10.355	0.414	0.293	11.455	10.146	1.029	10.148	-
2965200	11	10.136	5.022	18.08	13.058	3.902	12.268	9.454	1.490	10.158	13.194
4063049	1	10.044	10.044	10.044	0	-	-	10.044	-	-	-
5670818	1	10.044	10.044	10.044	0	-	-	10.044	-	-	-

Table 60: Males with the Largest Number of Samples

Males w/ the most samples	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
5636942	72	16.936	10.044	21.093	11.049	2.635	17.453	16.709	1.187	16.952	17.548
688912	61	15.791	9.04	23.102	14.062	3.172	16.469	15.472	1.229	15.799	16.539
311139	59	14.838	6.027	21.093	15.066	3.501	15.600	14.370	1.308	14.887	15.835
634149	58	19.621	6.027	25.111	19.084	3.526	20.395	19.199	1.260	19.709	20.783
5635620	57	26.239	19.084	33.146	14.062	3.332	26.977	26.029	1.137	26.241	27.014
3564506	51	19.537	5.022	29.129	24.107	4.717	20.644	18.770	1.373	19.719	21.362
5635864	50	20.631	14.062	27.12	13.058	3.292	21.412	20.370	1.176	20.635	21.469
5636500	50	20.551	15.067	27.12	12.053	2.701	21.191	20.379	1.140	20.550	21.212
1149149	49	15.743	5.022	23.102	18.08	3.359	16.548	15.297	1.300	15.822	16.910
5091620	49	22.529	16.071	32.142	16.071	3.307	23.321	22.293	1.158	22.530	23.357
701579	47	22.976	0.001	34.151	34.15	8.056	24.948	15.504	5.649	64.346	155.809
70197	47	22.867	14.062	32.142	18.08	3.969	23.839	22.515	1.198	22.879	23.953
3537106	45	26.830	23.102	36.16	13.058	2.620	27.486	26.712	1.098	26.827	27.473
3537138	45	18.883	13.058	25.111	12.053	2.756	19.574	18.689	1.157	18.884	19.604
354422	45	22.390	5.022	33.146	28.124	4.222	23.447	21.786	1.314	22.596	24.300
3537109	44	22.280	13.058	27.12	14.062	2.395	22.887	22.139	1.125	22.290	22.980
4499493	44	23.011	10.044	32.142	22.098	4.848	24.239	22.469	1.256	23.047	24.487
545541	44	21.070	8.036	31.138	23.102	5.383	22.434	20.268	1.348	21.168	22.954
83171	44	19.975	16.071	28.124	12.053	1.928	20.463	19.889	1.097	19.973	20.456
3537155	43	17.509	10.044	25.111	15.067	3.702	18.458	17.106	1.249	17.524	18.604
3577543	43	20.673	13.058	32.142	19.084	4.120	21.729	20.301	1.210	20.664	21.739
501798	43	24.013	20.089	30.133	10.044	2.255	24.591	23.912	1.097	24.012	24.598
5121327	43	19.551	15.067	25.111	10.044	2.960	20.311	19.336	1.162	19.551	20.341
5635756	43	17.192	12.053	23.102	11.049	2.567	17.851	17.002	1.164	17.195	17.899
5636034	43	25.479	19.084	32.142	13.058	3.093	26.272	25.296	1.129	25.479	26.304
639601	43	25.695	20.089	39.173	19.084	3.636	26.628	25.461	1.144	25.688	26.615

Table 61: Females with the Largest Number of Samples

Females w/ the most samples	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
1585765	32	8.049	5.022	13.462	8.44	2.733	8.868	7.608	1.407	8.050	9.007
389452	28	9.025	5.022	13.462	8.44	2.351	9.782	8.715	1.316	9.037	9.936
332281	26	8.054	5.022	11.049	6.027	1.767	8.646	7.857	1.260	8.061	8.750
5431760	24	6.906	5.022	10.044	5.022	1.367	7.384	6.782	1.212	6.904	7.408
5637878	24	6.320	5.022	8.036	3.014	1.046	6.686	6.238	1.179	6.319	6.708
2546970	21	18.702	9.04	22.098	13.058	2.885	19.787	18.416	1.215	18.752	20.254
531468	21	7.087	5.022	9.04	4.018	1.314	7.581	6.970	1.207	7.088	7.633
5638334	21	6.601	5.022	9.04	4.018	1.213	7.057	6.494	1.204	6.601	7.102
5635776	20	6.178	5.022	8.036	3.014	0.993	6.561	6.106	1.168	6.176	6.574
2032504	18	6.473	5.022	10.044	5.022	1.204	6.967	6.379	1.188	6.469	6.965
5518631	17	6.795	5.022	9.04	4.018	1.152	7.283	6.700	1.191	6.797	7.345
5637699	17	6.322	5.022	11.049	6.027	1.803	7.085	6.125	1.282	6.305	7.061
3575663	16	13.092	7.031	19.084	12.053	3.240	14.512	12.706	1.293	13.104	14.806
4519206	16	7.079	5.385	9.7	4.315	1.031	7.531	7.010	1.154	7.078	7.556
4836371	16	6.717	5.022	10.044	5.022	1.629	7.431	6.549	1.256	6.711	7.470
614170	16	5.785	5.022	7.031	2.009	0.676	6.082	5.749	1.123	5.785	6.095
513521	15	7.398	5.022	11.049	6.027	2.065	8.337	7.139	1.317	7.396	8.486
5635896	15	6.228	5.022	8.036	3.014	1.152	6.751	6.129	1.203	6.227	6.806
5636096	15	7.031	5.022	12.053	7.031	1.860	7.877	6.840	1.264	7.017	7.870
5637913	15	5.893	5.022	7.031	2.009	0.838	6.274	5.838	1.152	5.892	6.299
723678	15	5.692	5.022	8.036	3.014	0.904	6.103	5.632	1.159	5.689	6.100

Appendix C Respirable dust and crystalline silica data analysis methodology

Data analysis was undertaken for respirable dust and respirable crystalline silica for both the Coal Mines and Mineral Mines and Quarries. The analysis was performed by calendar year on the data sets received from RSHQ. Invalid samples were removed where applicable.

The values calculated in the tables include:

- No of Samples- the number of valid sample available in the data set
- Normal Parametric mean- average or arithmetic mean
- Minimum- the minimum value observed. Any value of "0" listed in the database was revised to 0.001 to reflect the limits of reporting
- Maximum- the maximum value observed.
- Standard deviation- the normal parametric standard deviation
- Normal Parametric 95% UCL- The normal parametric 95% upper confidence limit of the data set. Referred to in the text as "UCL".
- Geometric Mean- the geometric mean of the data set
- Geometric Std Dev- The geometric standard deviation of the data set
- Lognormal Parametric MVUE- the lognormal parametric minimum variance unbiased estimator
- Lognormal parametric 95% UCL- The lognormal parametric 95% upper confidence limit. Referred to in the text as "Log UCL". A minimum of 3 samples is required to calculate this value

A stoplight system was used in the tables based on the current occupational exposure limit (OEL) for the substance being analysed.

Table 62: Icon Set Meanings for Total Dust, Respirable Crystalline Silica and Diesel Particulate Matter Exposures

	Below half the OEL
	Over half the OEL, but does not exceed the OEL
	Above the OEL

Appendix D Coal mines—Respirable Coal Dust (RCD)

There are many exposure samples for coal mines, especially underground which provides a more robust analysis. The number of samples has increased significantly since 2016.

The average exposure level for underground coal mines has decreased over the year. The average exposure was above 1.5 mg/m^3 before 2015 which indicates that historic exposures were high and more miners may develop mine dust lung disease in coming years.

Very little data exists for surface coal mines before 2017.

The longwall production and development production SEGs historically have had high exposures which have decreased in recent years.

Ventilation control device (VCD) installer exposures are still not as well controlled.

This data set was found to have fewer errors and erroneous categorisations than the MMQ data, which is most likely a result of the increased emphasis on education for those collecting the samples and the greater focus of RSHQ on data verification and reporting in coal.

There were 40,567 valid samples included in the data set analysed for respirable coal dust for the coal mines.

There were 49 SEGs represented in the data including surface, underground and processing SEGs. These were grouped by SEG Code in the following table. SEG codes starting with QCP are coal processing (3,333 samples), QCS represents surface coal (15,081 samples) and QCU (22,153 samples) represents underground coal as cam be seen in Table 63. The average value of the underground samples as well as the normal parametric 95% UCL (UCL) and lognormal parametric 95% UCL (Log UCL) are all above 1.0 mg/m^3.

Table 63: RCD Exposure for Coal by SEG Group

	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Coal Processing	3333	0.228	0.01	4.90	4.90	0.319	0.237	0.146	2.435	0.217	0.224
Surface Coal	15081	0.152	0.00	63.00	63.00	0.648	0.161	0.087	2.470	0.131	0.133
Underground Coal	22153	1.028	0.01	39.00	39.00	1.597	1.045	0.579	2.905	1.023	1.039
Total Coal	40567	0.637	0.00	63.00	63.00	1.320	0.647	0.255	3.848	0.633	0.643

Table 64 shows the breakdown of each of the underground coal SEGs. The longwall production SEG average, UCL and Log UCL are all above the 1.5 mg/m^3 exposure standard. The geometric mean for this SEG is also above 1.0 mg/m^3. Several SEGs have an SEG average, UCL and Log UCL above half the OEL including development production, ERZ controller, stone drivage, underground maintenance and VCD installer.

A further group of SEGs have an average below half the OEL, but UCL and Log UCL above half the OEL including belt splicers, second support and shift coordinator.

Table 64: RCD Exposure for Underground Coal by SEG

Underground Coal SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Administration	30	0.172	0.05	0.80	0.75	0.151	0.219	0.133	1.996	0.167	0.221
Belt Splicers	127	0.531	0.05	19.00	18.95	1.690	0.780	0.287	2.411	0.420	0.498
Boilermaker (Surface)	8	0.258	0.06	0.72	0.67	0.237	0.417	0.181	2.445	0.253	0.783
Control Room Operator	33	0.055	0.02	0.10	0.08	0.018	0.060	0.052	1.356	0.054	0.060
Development Production	6127	1.076	0.02	39.00	38.98	1.690	1.111	0.673	2.464	1.010	1.035
ERZ Controller	1352	0.756	0.02	11.80	11.78	0.889	0.796	0.507	2.442	0.754	0.793
Gas Drainage	236	0.241	0.03	1.84	1.81	0.277	0.271	0.156	2.476	0.234	0.266
Longwall Moves	819	0.542	0.01	8.50	8.49	0.709	0.583	0.372	2.248	0.516	0.546
Longwall Production	5947	1.580	0.03	34.80	34.77	1.853	1.620	1.046	2.523	1.606	1.646
Outbye Construction / Infrastructure	1527	0.653	0.01	25.00	25.00	1.342	0.710	0.365	2.690	0.595	0.628
Outbye Supplies	39	0.292	0.05	0.72	0.67	0.199	0.346	0.230	2.053	0.296	0.380
Production support / bullgang	828	0.534	0.04	26.56	26.52	1.052	0.594	0.373	2.151	0.500	0.528
Resin Worker	15	0.287	0.10	1.20	1.10	0.277	0.413	0.217	2.057	0.276	0.439
Returns	28	0.620	0.10	2.00	1.90	0.399	0.748	0.516	1.896	0.627	0.813
Second Support	1029	0.730	0.03	24.00	23.97	1.508	0.807	0.384	2.772	0.646	0.692
Shift Co-ordinator / Management	189	0.637	0.01	5.16	5.15	0.946	0.751	0.240	4.307	0.690	0.921
Stone Drivage	257	0.794	0.05	6.90	6.85	1.119	0.909	0.468	2.591	0.734	0.835
Surface Maintenance	280	0.267	0.01	13.00	12.99	0.953	0.361	0.128	2.553	0.198	0.223
Surface other	285	0.118	0.01	0.90	0.90	0.116	0.129	0.083	2.310	0.118	0.131
Underground Maintenance	2182	0.775	0.01	19.60	19.59	1.192	0.817	0.472	2.669	0.765	0.800
Underground other	194	0.470	0.01	7.60	7.59	0.724	0.556	0.256	2.926	0.453	0.541
VCD Installer	621	1.196	0.05	21.00	20.95	2.287	1.347	0.573	3.053	1.067	1.181

Figure 30: Average RCD Exposure for Underground Coal by SEG

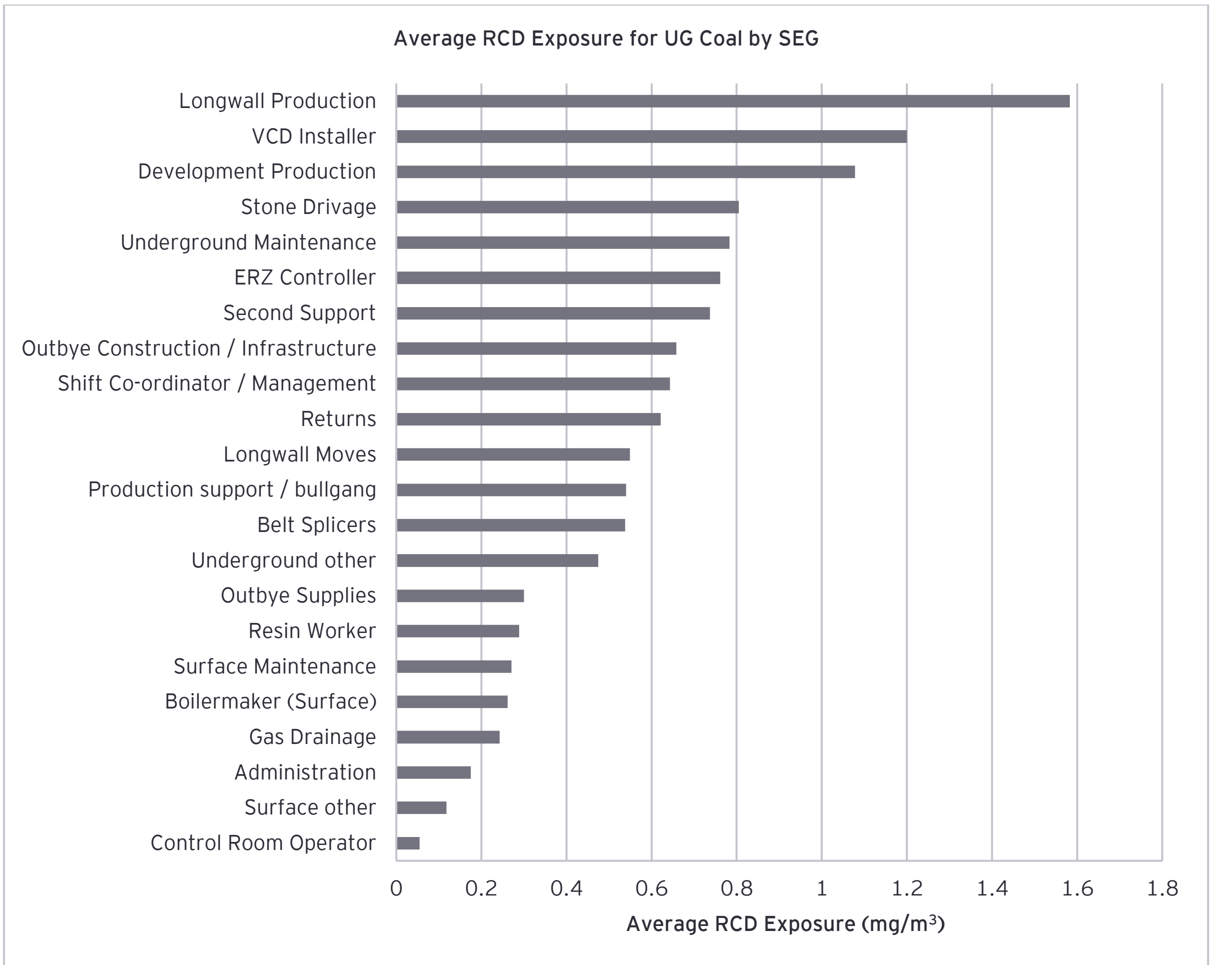


Table 65 shows the underground coal RCD exposure by year. The number of samples taken per year has increased while the average exposure levels have decreased. These numbers were calculated based on the SEGs with a SEG Code starting with QCU.

Table 65: RCD Exposure for Underground Coal SEGs by Year

Underground Coal by Year	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
1999	28	1.693	0.4	3.5	3.1	0.862	1.970	1.465	1.781	1.718	2.157
2000	112	2.308	0.4	28.3	27.9	3.024	2.782	1.716	1.981	2.162	2.460
2001	215	1.547	0.1	34.8	34.7	2.630	1.843	1.038	2.266	1.448	1.625
2002	243	1.846	0.05	22.8	22.75	2.191	2.078	1.209	2.521	1.848	2.100
2003	399	1.659	0.2	21.6	21.4	1.958	1.821	1.171	2.170	1.579	1.707
2004	353	1.520	0.05	17.9	17.85	1.844	1.682	1.039	2.276	1.456	1.593
2005	428	1.538	0.05	14.7	14.65	1.706	1.674	0.996	2.596	1.568	1.731
2006	575	1.466	0.05	16.72	16.67	1.724	1.584	0.951	2.540	1.466	1.592
2007	863	1.368	0.05	20	19.95	1.582	1.456	0.872	2.599	1.374	1.473
2008	589	0.969	0.05	9.6	9.55	1.055	1.041	0.643	2.483	0.971	1.051
2009	588	1.011	0.05	9	8.95	1.090	1.085	0.641	2.673	1.038	1.133
2010	637	1.004	0.05	10.1	10.05	1.123	1.077	0.588	2.967	1.062	1.170
2011	574	1.185	0.05	18	17.95	1.783	1.307	0.671	2.864	1.166	1.285
2012	1001	1.152	0.05	29	28.95	2.191	1.266	0.578	3.061	1.080	1.170
2013	771	1.368	0.05	39	38.95	2.477	1.515	0.734	2.861	1.273	1.384
2014	944	1.772	0.05	29	28.95	2.698	1.917	0.924	3.129	1.769	1.925
2015	1312	1.881	0.05	27	26.95	2.166	1.979	1.179	2.782	1.988	2.114
2016	2739	1.338	0.05	37	36.95	1.713	1.392	0.898	2.397	1.316	1.361
2017	2673	0.664	0.01	13	12.99	0.757	0.688	0.456	2.393	0.668	0.691
2018	2626	0.568	0.05	19	18.95	0.683	0.590	0.396	2.380	0.577	0.597
2019	2490	0.485	0.005	26.561	26.556	0.787	0.511	0.314	2.560	0.488	0.508
2020	1993	0.416	0.005	15.723	15.718	0.683	0.441	0.258	2.634	0.412	0.431
Total	22153	1.028	0.005	39	38.995	1.597	1.045	0.579	2.905	1.023	1.039

Figure 31: RCD Exposure for Underground Coal SEGs by Year

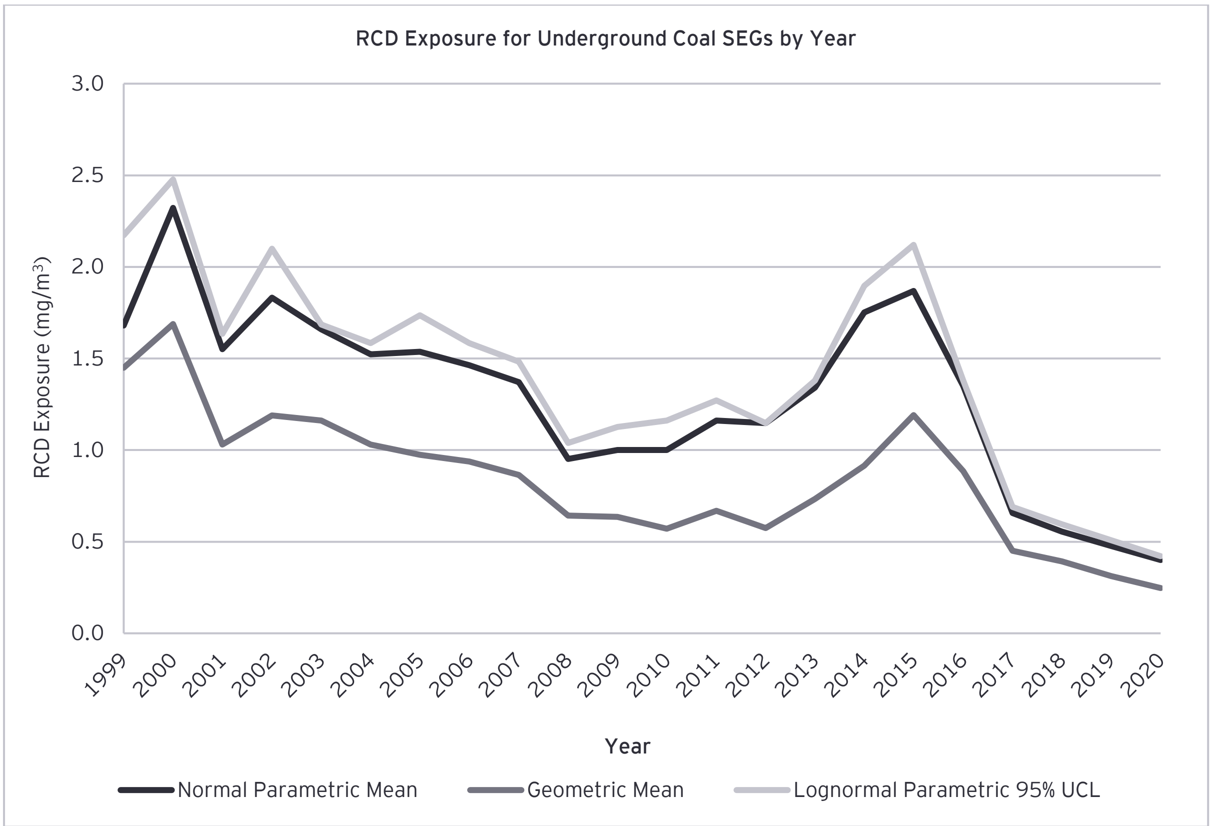


Table 66 shows the breakdown of each of the surface coal SEGs. Collectively, these exposures are sufficiently below half of the OEL.

Table 66: RCD Exposure for Surface Coal by SEG

Surface Coal SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Administration	112	0.072	0.01	0.91	0.91	0.103	0.088	0.053	2.036	0.068	0.078
Blast crew	1432	0.168	0.01	5.10	5.09	0.258	0.179	0.113	2.288	0.160	0.167
Blast hole drillers	1020	0.160	0.01	6.77	6.76	0.328	0.177	0.103	2.370	0.149	0.157
Boilermaker	199	0.553	0.01	10.00	10.00	1.067	0.678	0.219	3.670	0.506	0.640
Coal removal	1503	0.115	0.01	3.30	3.30	0.157	0.122	0.082	2.203	0.111	0.116
Dozer Push	2	0.090	0.06	0.12	0.06	0.042	0.279	0.085	1.633	0.090	-
Dragline	770	0.137	0.01	3.00	2.99	0.206	0.150	0.087	2.506	0.133	0.142
Emergency response personnel	15	0.057	0.02	0.11	0.09	0.024	0.068	0.052	1.524	0.057	0.071
Exploration drillers	536	0.163	0.00	2.99	2.99	0.247	0.180	0.089	2.893	0.157	0.174
Field Maintenance	1557	0.193	0.01	16.00	16.00	0.688	0.221	0.093	2.590	0.146	0.154
Open cut inspection services	355	0.077	0.01	1.01	1.01	0.086	0.085	0.056	2.184	0.076	0.083
Open cut other	1716	0.173	0.01	18.40	18.40	0.566	0.196	0.095	2.580	0.149	0.156
Pre-strip and overburden removal	1770	0.111	0.01	1.66	1.66	0.130	0.116	0.078	2.228	0.107	0.111
Production Dozing	400	0.113	0.00	0.80	0.80	0.103	0.122	0.087	2.061	0.112	0.121
Pump Crew	10	0.117	0.01	0.38	0.37	0.119	0.186	0.070	3.125	0.122	0.482
Road maintenance	720	0.101	0.01	4.70	4.69	0.215	0.114	0.067	2.177	0.091	0.096
Service crew	503	0.274	0.01	63.00	62.99	2.889	0.486	0.079	2.442	0.118	0.128
Tech services	536	0.126	0.00	2.40	2.40	0.237	0.143	0.068	2.649	0.110	0.120
Tyre fitters	388	0.189	0.01	3.81	3.81	0.288	0.213	0.111	2.728	0.183	0.204
Warehousing	215	0.122	0.01	1.40	1.40	0.145	0.139	0.085	2.238	0.117	0.131
Workshop	1322	0.125	0.01	5.40	5.40	0.311	0.139	0.072	2.400	0.105	0.111

Figure 32: Average RCD Exposure for Surface Coal by SEG

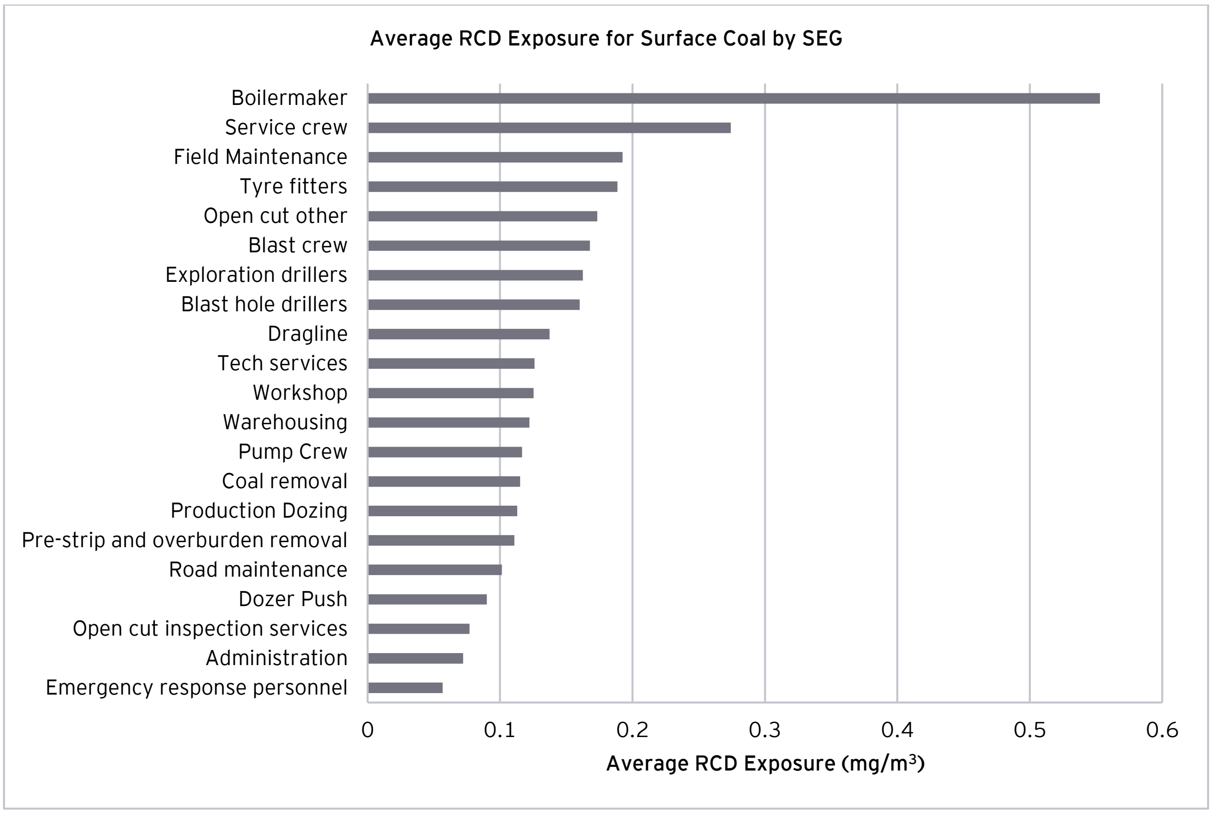


Table 67 shows the surface coal exposure by year for the 15,081 samples available. The number of samples available before 2017 is extremely small and insufficient to adequately judge the exposure of these SEGs. The number of samples has increased substantially since 2017.

Table 67: RCD Exposure for Surface Coal by Year

Surface Coal by Year	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2002	1	1.800	1.80	1.80	0.00	-	-	1.800	-	-	-
2004	1	0.400	0.40	0.40	0.00	-	-	0.400	-	-	-
2006	1	0.200	0.20	0.20	0.00	-	-	0.200	-	-	-
2008	1	0.110	0.11	0.11	0	-	-	0.110	-	-	-
2009	8	0.153	0.1	0.26	0.16	0.073	0.201	0.139	1.574	0.152	0.226
2010	3	0.280	0.12	0.52	0.4	0.212	0.637	0.232	2.105	0.277	48.874
2011	4	0.375	0.1	0.7	0.6	0.250	0.669	0.303	2.266	0.385	5.717
2012	40	0.305	0.05	2.4	2.35	0.419	0.417	0.177	2.714	0.287	0.424
2013	15	0.293	0.05	0.9	0.85	0.270	0.416	0.191	2.659	0.296	0.621
2014	10	0.560	0.1	1.6	1.5	0.595	0.905	0.342	2.813	0.543	1.730
2015	8	0.356	0.05	1.4	1.35	0.435	0.648	0.226	2.663	0.337	1.266
2016	24	0.352	0.05	1.6	1.55	0.464	0.515	0.181	3.080	0.327	0.631
2017	3033	0.218	0.01	18.4	18.39	0.616	0.237	0.127	2.333	0.182	0.187
2018	3833	0.170	0.005	9.8	9.795	0.345	0.179	0.109	2.244	0.151	0.155
2019	4103	0.116	0.004	10	9.996	0.253	0.123	0.071	2.455	0.107	0.110
2020	3996	0.118	0.003	63	62.997	1.051	0.145	0.062	2.352	0.090	0.093
Total	15081	0.152	0.00	63.00	63.00	0.648	0.161	0.087	2.470	0.131	0.133

Table 68 shows coal processing exposure by SEB for the 3,333 samples. Similar to the surface SEGs, collectively the averages of these SEGS are also below half the exposure limit.

Table 68: RCD Exposure for Processing by SEG

Coal Processing SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Belt Splicers	28	0.175	0.03	0.87	0.84	0.189	0.235	0.119	2.334	0.168	0.246
CHPP dozer	196	0.175	0.02	2.32	2.30	0.264	0.206	0.115	2.256	0.159	0.180
CHPP laboratory	683	0.348	0.01	4.00	3.99	0.426	0.375	0.218	2.605	0.345	0.373
CHPP maintenance	796	0.221	0.01	4.90	4.90	0.328	0.240	0.140	2.454	0.209	0.224
CHPP other	167	0.155	0.02	1.16	1.15	0.167	0.176	0.111	2.149	0.149	0.168
CHPP production	1463	0.193	0.01	4.73	4.73	0.257	0.204	0.132	2.265	0.185	0.193

Figure 33: Average RCD Exposure for Coal Processing by SEG

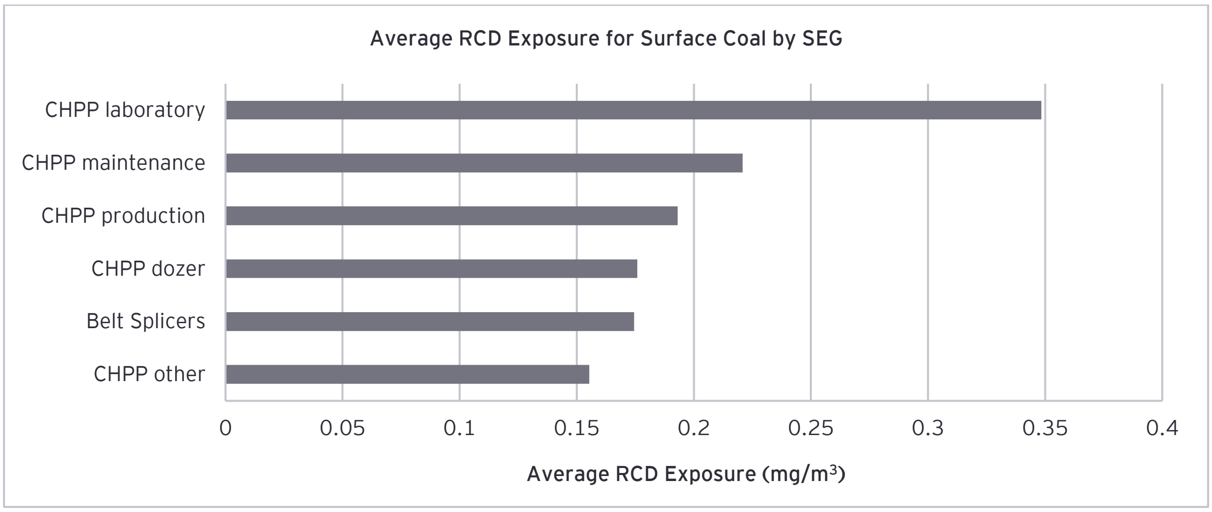


Table 69 shows the coal processing SEGs by year. Similar to the surface SEGs, there were very few samples taken prior to 2017, so this data is insufficient to adequately judge the exposure of these populations.

Table 69: RCD Exposure for Coal Processing by Year

Coal Processing by Year	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2001	5	0.380	0.10	1.20	1.10	0.460	0.819	0.249	2.531	0.346	3.259
2002	3	0.633	0.10	1.00	0.90	0.473	1.430	0.431	3.560	0.696	-
2003	4	0.200	0.10	0.30	0.20	0.082	0.296	0.186	1.578	0.201	0.515
2004	3	0.533	0.40	0.70	0.30	0.153	0.791	0.519	1.325	0.533	1.231
2007	9	0.182	0.10	0.33	0.23	0.074	0.228	0.170	1.496	0.182	0.248
2008	1	0.400	0.40	0.40	0.00	-	-	0.400	-	-	-
2009	8	0.200	0.10	0.70	0.60	0.207	0.339	0.152	1.999	0.186	0.391
2010	18	0.217	0.10	0.50	0.40	0.134	0.272	0.184	1.787	0.215	0.291
2012	73	0.275	0.05	3.00	2.95	0.392	0.351	0.183	2.232	0.252	0.308
2013	32	0.314	0.05	1.70	1.65	0.356	0.421	0.210	2.339	0.296	0.422
2014	38	0.447	0.05	4.90	4.85	0.828	0.674	0.228	2.912	0.394	0.617
2015	21	0.321	0.05	0.90	0.85	0.208	0.400	0.260	2.033	0.329	0.472
2016	37	0.411	0.05	4.00	3.95	0.699	0.605	0.233	2.548	0.355	0.515
2017	668	0.287	0.03	3.70	3.67	0.357	0.310	0.190	2.352	0.273	0.292
2018	786	0.257	0.01	3.40	3.40	0.324	0.276	0.166	2.429	0.246	0.263
2019	798	0.185	0.01	4.73	4.73	0.296	0.203	0.116	2.460	0.174	0.186
2020	829	0.164	0.01	2.13	2.12	0.183	0.175	0.116	2.227	0.160	0.169
Total	3333	0.228	0.01	4.90	4.90	0.319	0.237	0.146	2.435	0.217	0.224

Table 70 shows the exposure of the underground longwall production SEG by year. This data shows a downward trend in the in average, geometric mean, UCL and Log UCL of the data, though these values were well over the current OEL for a number of years. Some of the UCL and Log UCLs are even over the former 3.0mg/m^3 exposure standard. An increase in the number of samples taken over the years can also be seen.

Table 70: RCD Exposure for LW Production SEG by Year

Longwall Production SEG by Year	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
1999	13	2.085	0.70	3.50	2.80	0.910	2.534	1.872	1.670	2.111	2.911
2000	61	2.813	0.40	28.30	27.90	3.875	3.642	2.017	2.063	2.608	3.167
2001	76	2.539	0.20	34.80	34.60	4.124	3.327	1.649	2.363	2.371	2.945
2002	103	2.120	0.20	8.30	8.10	1.595	2.381	1.590	2.238	2.190	2.590
2003	150	2.171	0.30	12.10	11.80	1.867	2.423	1.625	2.131	2.158	2.448
2004	98	1.633	0.05	7.20	7.15	1.431	1.873	1.186	2.294	1.666	1.993
2005	136	1.640	0.10	12.50	12.40	1.374	1.836	1.315	1.958	1.644	1.843
2006	188	1.577	0.05	16.72	16.67	1.587	1.768	1.158	2.210	1.582	1.782
2007	287	1.848	0.10	20.00	19.90	1.912	2.035	1.256	2.521	1.922	2.160
2008	159	1.392	0.10	8.00	7.90	1.202	1.549	1.006	2.345	1.442	1.663
2009	230	1.259	0.05	6.00	5.95	1.090	1.378	0.814	2.852	1.405	1.643
2010	180	1.506	0.05	9.00	8.95	1.280	1.664	1.048	2.582	1.637	1.912
2011	109	1.731	0.05	12.00	11.95	1.717	2.004	1.150	2.741	1.899	2.370
2012	147	1.804	0.05	14.00	13.95	2.278	2.115	1.051	2.923	1.857	2.282
2013	179	2.001	0.10	12.00	11.90	1.979	2.246	1.289	2.707	2.108	2.490
2014	304	2.729	0.05	25.87	25.82	3.355	3.046	1.649	2.806	2.800	3.195
2015	565	2.581	0.05	27.00	26.95	2.595	2.761	1.840	2.362	2.661	2.867
2016	1018	1.719	0.05	19.07	19.02	1.490	1.796	1.299	2.146	1.738	1.822
2017	742	0.938	0.05	13.00	12.95	0.944	0.995	0.703	2.164	0.947	1.002
2018	512	0.879	0.10	4.90	4.80	0.618	0.924	0.706	1.965	0.887	0.940
2019	400	0.747	0.05	3.30	3.25	0.481	0.787	0.594	2.087	0.777	0.836
2020	290	0.602	0.03	2.20	2.17	0.446	0.645	0.449	2.286	0.631	0.698

Figure 34: RCD Exposure for Longwall Production SEG by Year

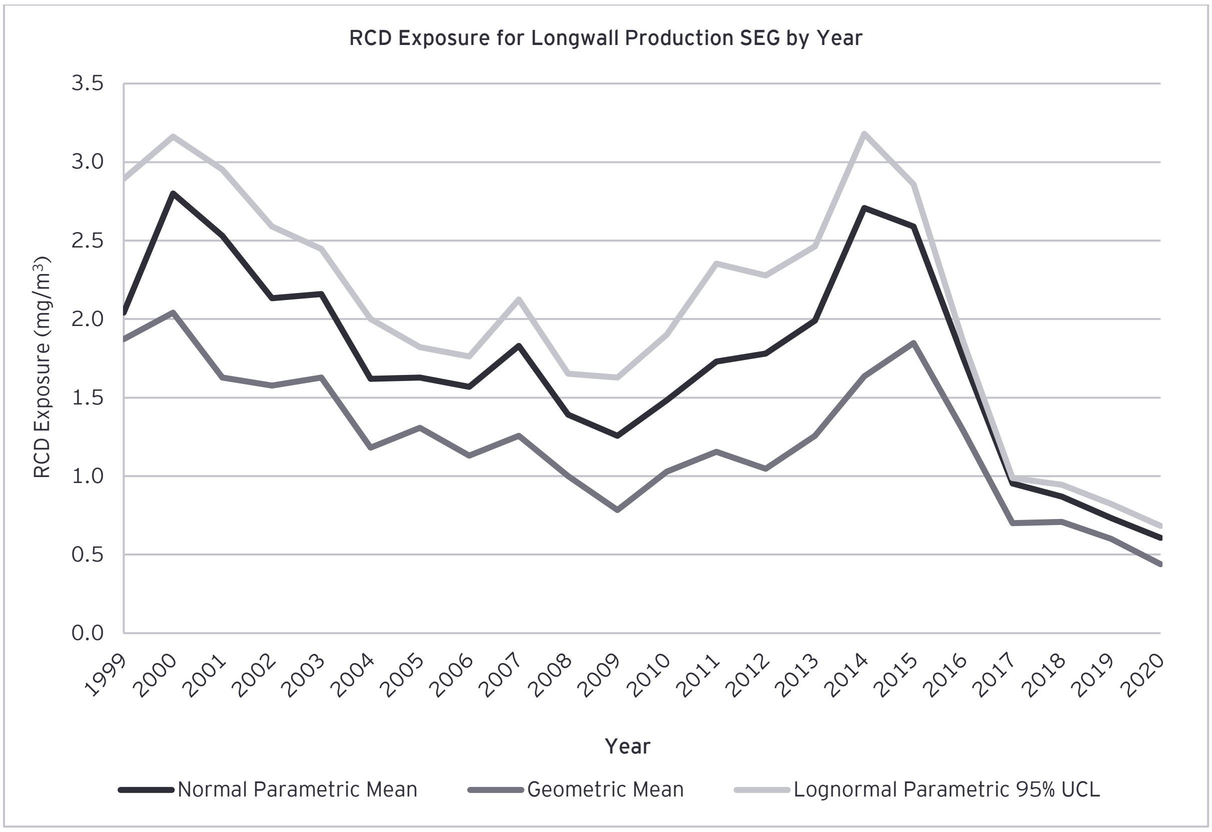


Table 71 shows the Exposure of the underground Development Production SEG by year. This data shows a downward trend in the in average, geometric mean, UCL and Log UCL of the data. While some of the UCL and Log UCLs are over the current exposure standard, none of the years were over the 3.0 mg/m^3 exposure standard. An increase in the number of samples taken over the years can also be seen.

Table 71: RCD Exposure for Development Production SEG by Year

Development Production SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2000	19	1.911	0.60	6.60	6.00	1.622	2.556	1.474	2.013	1.853	2.701
2001	73	1.033	0.10	7.50	7.40	0.986	1.225	0.786	2.091	1.026	1.229
2002	85	1.513	0.10	22.80	22.70	2.689	1.998	0.929	2.390	1.350	1.660
2003	155	1.564	0.30	21.60	21.30	2.403	1.883	1.037	2.186	1.405	1.599
2004	171	1.548	0.10	17.90	17.80	2.255	1.833	0.980	2.366	1.416	1.628
2005	202	1.647	0.05	14.70	14.65	1.947	1.873	0.967	2.846	1.665	1.968
2006	275	1.677	0.05	16.50	16.45	2.031	1.880	1.016	2.714	1.668	1.905
2007	389	1.287	0.05	11.70	11.65	1.424	1.406	0.860	2.395	1.258	1.379
2008	263	0.938	0.05	9.60	9.55	1.041	1.044	0.651	2.307	0.921	1.025
2009	255	0.924	0.05	9.00	8.95	1.157	1.044	0.599	2.466	0.898	1.013
2010	203	1.158	0.05	10.10	10.05	1.221	1.299	0.736	2.678	1.192	1.389
2011	222	1.278	0.05	10.50	10.45	1.412	1.434	0.821	2.625	1.304	1.503
2012	227	1.423	0.05	29.00	28.95	2.667	1.715	0.768	2.805	1.302	1.519
2013	166	1.599	0.10	39.00	38.90	3.451	2.042	0.888	2.536	1.364	1.596
2014	156	1.733	0.05	29.00	28.95	2.947	2.123	0.904	2.963	1.622	1.987
2015	260	1.501	0.05	12.00	11.95	1.643	1.670	1.044	2.327	1.489	1.660
2016	785	1.262	0.10	37.00	36.90	2.168	1.390	0.826	2.248	1.146	1.215
2017	627	0.706	0.08	6.80	6.72	0.681	0.751	0.538	2.014	0.688	0.726
2018	600	0.634	0.05	4.00	3.95	0.496	0.667	0.502	1.981	0.634	0.669
2019	562	0.528	0.04	3.60	3.56	0.427	0.558	0.415	2.009	0.529	0.560
2020	432	0.434	0.02	2.19	2.17	0.353	0.462	0.336	2.045	0.434	0.464

Figure 35: RCD Exposure for Development Production SEG by Year

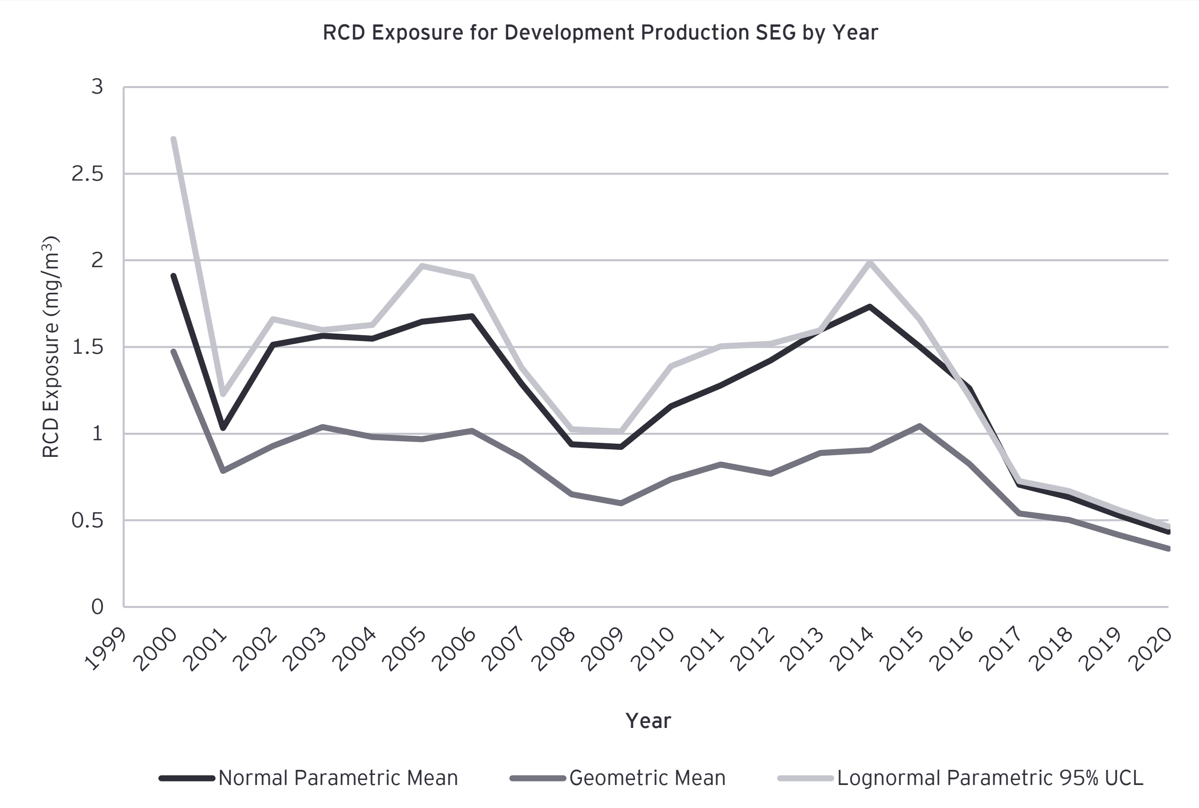


Table 72 shows the RCD exposure for the ventilation control device installers by year. While the number of samples has increased since 2017 there are still a relatively small number of samples. The variability of these samples causes very high UCL and Log UCLs in some years. With at least one of the values being above 3.0 mg/m^3 in six of the years. Since 2017 these average, UCL and Log UCLs are still above half of the OEL and more emphasis should be placed on lowering the exposure of this group.

Table 72: RCD Exposure for VCD Installers by Year

VCD Installer	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2004	13	2.069	0.60	4.50	3.90	1.159	2.642	1.761	1.856	2.096	3.172
2005	3	5.833	0.60	9.40	8.80	4.631	13.640	3.484	4.607	6.769	-
2007	12	0.768	0.15	4.40	4.25	1.164	1.371	0.473	2.382	0.662	1.380
2008	8	0.721	0.24	2.40	2.16	0.736	1.214	0.525	2.173	0.679	1.654
2009	7	0.411	0.20	1.00	0.80	0.269	0.609	0.362	1.659	0.403	0.682
2010	12	0.383	0.10	1.30	1.20	0.333	0.556	0.293	2.105	0.376	0.671
2011	11	4.309	0.20	18.00	17.80	6.629	7.932	1.652	4.098	3.848	24.398
2012	48	1.954	0.20	13.00	12.80	2.553	2.573	1.066	2.957	1.883	2.801
2013	36	2.139	0.10	21.00	20.90	4.819	3.496	0.699	3.658	1.557	2.936
2014	35	1.664	0.05	6.90	6.85	1.785	2.174	0.831	3.793	1.932	3.800
2015	43	1.427	0.05	8.50	8.45	1.636	1.847	0.769	3.404	1.582	2.648
2016	33	2.042	0.10	21.00	20.90	3.974	3.214	0.876	3.331	1.743	3.155
2017	79	0.657	0.05	4.70	4.65	0.745	0.797	0.425	2.537	0.650	0.824
2018	85	0.747	0.05	4.50	4.45	0.753	0.883	0.517	2.366	0.745	0.913
2019	112	0.724	0.07	5.80	5.73	0.923	0.869	0.449	2.517	0.684	0.829
2020	84	0.883	0.05	15.72	15.67	1.993	1.245	0.381	3.095	0.713	0.966

Figure 36: RCD Exposure for VCD Installer SEG by Year

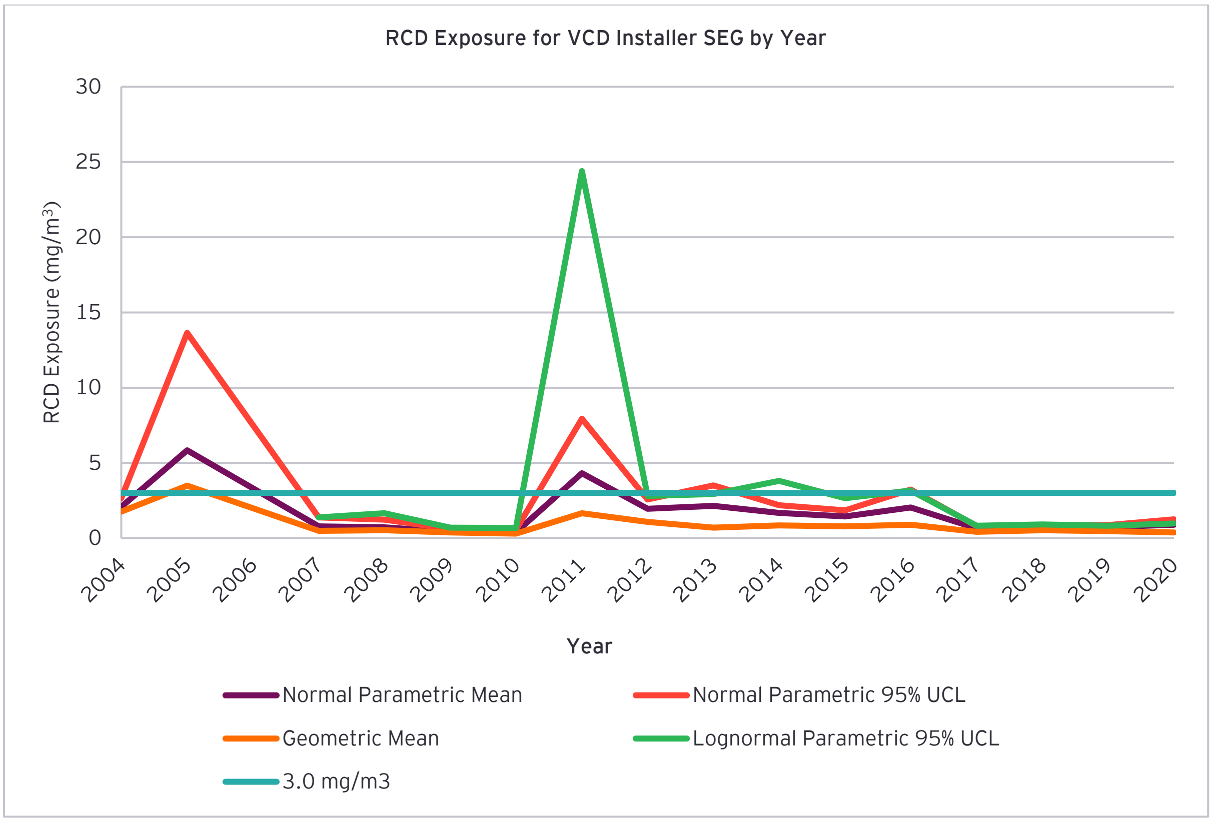


Table 73 shows the exposures by mine number over the 20 year time period. It should be noted that while this data represents historic exposure and may correlate to the incidence of disease. It may not necessarily corelate to current compliance as some mine's exposure has changed substantially in the last three years.

Table 73: RCD Exposure for Underground SEGs by Mine Number

UG SEGs by Mine Number	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
5	3067	0.956	0.01	26.56	26.55	1.530	1.002	0.504	3.146	0.972	1.019
6	687	0.882	0.05	34.80	34.75	1.856	0.998	0.450	3.118	0.858	0.947
7	733	1.107	0.05	24.00	23.95	2.055	1.232	0.612	2.772	1.028	1.116
8	690	1.427	0.05	25.00	24.95	2.099	1.559	0.803	2.935	1.431	1.568
10	2388	1.061	0.05	29.00	28.95	1.625	1.116	0.632	2.714	1.041	1.087
12	1613	1.653	0.02	37.00	36.98	2.133	1.741	1.053	2.639	1.686	1.775
13	1584	0.800	0.05	15.00	14.95	1.074	0.845	0.504	2.484	0.762	0.799
21	1451	1.208	0.05	39.00	38.95	2.202	1.303	0.720	2.570	1.123	1.183
24	654	0.572	0.05	15.00	14.95	0.923	0.631	0.366	2.434	0.542	0.583
26	1330	1.132	0.05	14.70	14.65	1.424	1.196	0.719	2.559	1.117	1.179
31	1439	0.717	0.05	19.00	18.95	0.963	0.758	0.483	2.400	0.708	0.742
32	304	0.846	0.01	10.50	10.49	1.241	0.964	0.385	3.596	0.868	1.041
33	2506	1.105	0.01	20.00	20.00	1.371	1.150	0.611	3.206	1.204	1.270
34	3088	1.005	0.05	27.00	26.95	1.498	1.050	0.585	2.752	0.976	1.015
40	1	0.100	0.10	0.10	0.00	-	-	0.100	-	-	-
45	4	0.169	0.06	0.36	0.30	0.131	0.323	0.136	2.143	0.167	1.770
162	5	0.063	0.01	0.15	0.14	0.050	0.111	0.047	2.539	0.065	0.619
204	597	0.282	0.05	6.20	6.15	0.408	0.309	0.198	2.173	0.267	0.284
209	4	0.057	0.02	0.15	0.13	0.064	0.132	0.038	2.642	0.053	2.309
215	8	0.052	0.01	0.11	0.10	0.033	0.074	0.040	2.592	0.058	0.204

Table 74 shows the RCD exposure by mine number for the surface mines. It should be noted that many of these mines have extremely small number of samples collected.

Table 74: RCD Exposure for Surface SEGs by Mine Number

Surface SEGs by Mine Number	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
5	31	0.157	0.01	0.52	0.51	0.129	0.196	0.102	2.866	0.173	0.285
8	5	0.100	0.10	0.10	0.00	0.000	0.100	0.100	1.000	0.100	0.110
10	2	1.500	1.20	1.80	0.60	0.424	3.394	1.470	1.332	1.500	-
12	7	0.353	0.03	1.60	1.57	0.587	0.784	0.116	4.604	0.286	10.027
13	21	0.241	0.05	0.90	0.85	0.215	0.322	0.180	2.112	0.235	0.346
21	1	0.200	0.20	0.20	0.00	-	-	0.200	-	-	-
24	15	0.197	0.05	1.10	1.05	0.284	0.326	0.121	2.364	0.169	0.310
25	371	0.206	0.05	2.80	2.75	0.360	0.236	0.125	2.282	0.176	0.192
26	7	0.236	0.05	0.70	0.65	0.236	0.409	0.161	2.510	0.228	0.906
27	233	0.149	0.05	1.30	1.25	0.177	0.168	0.109	2.009	0.138	0.151
28	165	0.175	0.05	2.00	1.95	0.334	0.218	0.092	2.446	0.137	0.159
29	324	0.142	0.05	2.60	2.55	0.210	0.162	0.097	2.092	0.128	0.139
30	379	0.152	0.01	3.99	3.98	0.327	0.180	0.072	3.116	0.137	0.157
31	4	0.488	0.05	1.40	1.35	0.617	1.213	0.255	3.940	0.476	840.272
33	33	0.068	0.01	0.33	0.33	0.068	0.088	0.051	2.123	0.067	0.090
34	77	0.301	0.05	2.40	2.35	0.426	0.382	0.158	2.904	0.276	0.370
38	326	0.131	0.05	3.20	3.15	0.263	0.155	0.088	1.941	0.110	0.118
40	344	0.137	0.01	4.67	4.66	0.277	0.162	0.088	2.354	0.127	0.140
41	312	0.122	0.05	0.90	0.85	0.107	0.132	0.098	1.838	0.118	0.126
42	404	0.165	0.05	5.80	5.75	0.366	0.195	0.111	2.024	0.143	0.153
43	196	0.117	0.05	0.90	0.85	0.099	0.128	0.096	1.780	0.113	0.122
44	461	0.141	0.01	3.81	3.80	0.239	0.160	0.088	2.446	0.131	0.143
45	355	0.141	0.005	5.4	5.395	0.404	0.176	0.075	2.559	0.117	0.130
49	239	0.136	0.005	5.2	5.195	0.426	0.181	0.064	2.682	0.104	0.120
50	345	0.151	0.005	6.32	6.315	0.395	0.186	0.085	2.509	0.130	0.144
52	272	0.150	0.05	2	1.95	0.196	0.170	0.107	2.056	0.138	0.150
55	313	0.176	0.009	3.806	3.797	0.296	0.204	0.109	2.494	0.165	0.184
60	371	0.165	0.009	2	1.991	0.204	0.182	0.108	2.439	0.160	0.176
61	622	0.256	0.05	16	15.95	0.920	0.317	0.135	2.255	0.188	0.201
62	226	0.134	0.01	2.99	2.98	0.254	0.162	0.081	2.420	0.119	0.135
63	451	0.108	0.005	1.2	1.195	0.109	0.116	0.080	2.087	0.105	0.112
145	159	0.175	0.005	2	1.995	0.226	0.204	0.113	2.457	0.169	0.197
146	96	0.076	0.01	1.01	1	0.128	0.098	0.050	2.164	0.067	0.079
147	183	0.072	0.01	0.6	0.59	0.079	0.082	0.050	2.295	0.070	0.080
148	37	0.320	0.01	1.66	1.65	0.346	0.416	0.192	2.961	0.337	0.538
149	460	0.185	0.01	6.77	6.76	0.416	0.217	0.111	2.396	0.163	0.177
150	249	0.094	0.005	0.95	0.945	0.104	0.105	0.064	2.319	0.091	0.102
151	166	0.170	0.02	2.73	2.71	0.247	0.202	0.116	2.186	0.158	0.179
152	426	0.186	0.005	18.4	18.395	0.959	0.263	0.074	2.693	0.121	0.135
153	9	0.154	0.05	0.3	0.25	0.084	0.206	0.132	1.855	0.156	0.273
154	325	0.125	0.01	1.44	1.43	0.190	0.143	0.076	2.482	0.114	0.127
156	191	0.081	0.01	1.35	1.34	0.130	0.097	0.056	2.099	0.073	0.082
157	105	0.086	0.005	0.75	0.745	0.112	0.104	0.056	2.422	0.082	0.099
158	562	0.125	0.009	1.4	1.391	0.131	0.134	0.087	2.385	0.127	0.137
159	551	0.164	0.01	9.7	9.69	0.510	0.200	0.094	2.358	0.136	0.146
160	745	0.146	0.009	4.7	4.691	0.304	0.164	0.084	2.592	0.133	0.143
162	687	0.142	0.009	5.158	5.149	0.301	0.160	0.082	2.570	0.128	0.138
163	444	0.089	0.009	1.8	1.791	0.133	0.099	0.061	2.295	0.086	0.093
169	12	0.037	0.011	0.082	0.071	0.025	0.050	0.030	2.085	0.038	0.067
171	115	0.073	0.01	1.05	1.04	0.107	0.090	0.052	2.071	0.067	0.077
172	28	0.434	0.03	1.32	1.29	0.438	0.575	0.227	3.477	0.471	0.950
174	78	0.068	0.01	0.848	0.838	0.133	0.093	0.033	2.813	0.056	0.074
175	670	0.157	0.009	9.217	9.208	0.400	0.183	0.089	2.682	0.145	0.158
178	21	0.163	0.037	0.5	0.463	0.131	0.212	0.123	2.157	0.163	0.243
182	171	0.187	0.02	2.09	2.07	0.234	0.217	0.128	2.311	0.181	0.207
185	18	0.126	0.04	0.43	0.39	0.100	0.167	0.101	1.932	0.123	0.176
189	244	0.110	0.01	2.67	2.66	0.201	0.131	0.073	2.190	0.099	0.110
194	5	0.034	0.02	0.07	0.05	0.021	0.054	0.030	1.668	0.033	0.074
195	50	0.118	0.01	1.6	1.59	0.237	0.174	0.064	2.528	0.097	0.132
196	50	0.202	0.05	1.4	1.35	0.270	0.266	0.131	2.273	0.181	0.235
197	7	0.107	0.05	0.2	0.15	0.045	0.140	0.100	1.492	0.107	0.156
198	576	0.113	0.004	2.2	2.196	0.175	0.125	0.077	2.120	0.102	0.108
200	8	0.375	0.05	0.59	0.54	0.220	0.523	0.269	2.886	0.430	1.967
201	2	0.500	0.3	0.7	0.4	0.283	1.763	0.458	1.821	0.500	-
202	12	0.175	0.05	1.2	1.15	0.326	0.344	0.092	2.528	0.135	0.306
203	8	0.056	0.05	0.1	0.05	0.018	0.068	0.055	1.278	0.056	0.067
204	7	0.086	0.05	0.1	0.05	0.024	0.104	0.082	1.402	0.086	0.117
205	119	0.183	0.01	2.127	2.117	0.307	0.230	0.102	2.677	0.164	0.201
206	3	0.167	0.05	0.4	0.35	0.202	0.507	0.100	3.322	0.154	-
207	134	0.064	0.01	0.42	0.41	0.052	0.071	0.052	1.874	0.063	0.070
208	32	0.105	0.005	0.969	0.964	0.177	0.158	0.047	3.572	0.101	0.196
209	44	0.033	0.003	0.201	0.198	0.039	0.042	0.019	2.772	0.032	0.047
210	17	0.054	0.016	0.163	0.147	0.037	0.069	0.045	1.773	0.053	0.072
211	7	0.317	0.08	0.69	0.61	0.214	0.474	0.256	2.090	0.321	0.825
212	129	0.098	0.05	2.5	2.45	0.223	0.131	0.070	1.774	0.082	0.090
213	59	0.271	0.05	10	9.95	1.309	0.556	0.072	2.500	0.109	0.143
214	85	0.104	0.02	1.18	1.16	0.160	0.133	0.063	2.362	0.091	0.111
215	12	0.135	0.005	0.253	0.248	0.093	0.183	0.087	3.332	0.165	0.590
216	5	0.042	0.023	0.056	0.033	0.014	0.056	0.040	1.452	0.043	0.070
217	7	0.133	0.03	0.4	0.37	0.134	0.231	0.087	2.687	0.130	0.623
219	10	0.183	0.07	0.4	0.33	0.121	0.253	0.151	1.901	0.182	0.312
220	4	0.075	0.04	0.14	0.1	0.044	0.127	0.067	1.694	0.074	0.247
221	22	3.675	0.05	63	62.95	13.624	8.673	0.173	6.369	0.803	4.432
222	3	0.083	0.05	0.1	0.05	0.029	0.132	0.079	1.492	0.084	0.394

Table 75 shows the RCD exposure by mine number for coal processing, the vast majority of which show all parameters below half of the OEL. A few of these mines have a small number of samples collected.

Table 75: RCD Exposure for Processing SEGs by Mine Number

Processing SEGs by Mine Number	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
5	1	0.050	0.05	0.05	0.00	-	-	0.050	-	-	-
6	9	0.283	0.05	0.50	0.45	0.146	0.374	0.235	2.111	0.299	0.631
7	57	0.176	0.05	1.10	1.05	0.162	0.212	0.138	1.930	0.171	0.204
8	4	0.275	0.10	0.70	0.60	0.287	0.613	0.193	2.503	0.261	7.581
12	21	0.440	0.04	3.00	2.96	0.652	0.685	0.240	2.903	0.406	0.789
13	123	0.354	0.05	4.90	4.85	0.510	0.431	0.236	2.260	0.328	0.383
21	68	0.325	0.05	4.00	3.95	0.550	0.436	0.192	2.436	0.282	0.360
25	98	0.222	0.05	1.60	1.55	0.248	0.264	0.156	2.189	0.211	0.249
27	29	0.248	0.05	0.90	0.85	0.219	0.317	0.179	2.283	0.247	0.355
28	122	0.202	0.05	1.80	1.75	0.237	0.238	0.137	2.272	0.191	0.224
29	20	0.108	0.05	0.30	0.25	0.061	0.131	0.095	1.629	0.107	0.134
30	32	0.145	0.01	1.00	0.99	0.208	0.207	0.078	2.862	0.132	0.214
34	230	0.192	0.05	3.20	3.15	0.269	0.221	0.138	2.070	0.179	0.197
38	39	0.114	0.05	1.10	1.05	0.177	0.162	0.079	1.967	0.099	0.125
40	40	0.244	0.03	0.80	0.77	0.195	0.296	0.182	2.191	0.246	0.324
41	15	0.233	0.05	1.10	1.05	0.286	0.363	0.142	2.632	0.218	0.452
42	84	0.260	0.05	1.50	1.45	0.273	0.309	0.181	2.226	0.248	0.299
43	44	0.219	0.05	1.00	0.95	0.249	0.282	0.151	2.183	0.203	0.263
44	54	0.410	0.07	2.20	2.13	0.534	0.531	0.240	2.580	0.371	0.502
45	38	0.240	0.01	2.16	2.15	0.432	0.358	0.105	3.370	0.213	0.370
49	51	0.220	0.01	0.67	0.66	0.184	0.263	0.149	2.587	0.231	0.317
50	56	0.255	0.01	1.91	1.91	0.315	0.326	0.173	2.421	0.254	0.332
52	76	0.302	0.05	2	1.95	0.310	0.361	0.219	2.133	0.290	0.348
60	78	0.246	0.011	2.547	2.536	0.365	0.315	0.144	2.713	0.234	0.305
61	56	0.254	0.05	1.3	1.25	0.247	0.310	0.178	2.299	0.250	0.320
63	138	0.213	0.005	3	2.995	0.341	0.261	0.118	2.765	0.197	0.240
146	11	0.070	0.01	0.12	0.11	0.034	0.088	0.060	2.002	0.074	0.129
147	40	0.115	0.02	1.19	1.17	0.187	0.165	0.075	2.179	0.100	0.132
148	15	0.397	0.05	1.46	1.41	0.438	0.596	0.244	2.698	0.382	0.818
149	56	0.276	0.03	1.32	1.29	0.256	0.333	0.191	2.434	0.281	0.369
150	38	0.280	0.03	3.55	3.52	0.636	0.454	0.122	2.876	0.208	0.323
151	9	0.068	0.02	0.15	0.13	0.038	0.092	0.058	1.836	0.068	0.118
152	112	0.242	0.01	4.73	4.72	0.524	0.324	0.119	2.874	0.206	0.260
154	35	0.122	0.03	0.5	0.47	0.097	0.150	0.098	1.907	0.120	0.151
156	52	0.124	0.02	0.8	0.78	0.139	0.156	0.082	2.406	0.120	0.158
158	117	0.222	0.011	1.734	1.723	0.253	0.261	0.153	2.306	0.216	0.254
159	93	0.270	0.01	2.3	2.29	0.394	0.338	0.140	3.088	0.261	0.347
160	157	0.168	0.01	1.505	1.495	0.193	0.193	0.119	2.239	0.164	0.187
162	172	0.192	0.019	2.1	2.081	0.227	0.221	0.138	2.110	0.182	0.205
163	104	0.308	0.01	3.4	3.39	0.448	0.381	0.172	2.910	0.301	0.386
171	21	0.117	0.02	0.25	0.23	0.074	0.145	0.091	2.204	0.122	0.185
175	149	0.265	0.01	3.7	3.69	0.346	0.312	0.180	2.365	0.260	0.302
178	120	0.234	0.032	1.1	1.068	0.203	0.264	0.175	2.132	0.232	0.268
182	179	0.243	0.05	2.32	2.27	0.238	0.272	0.185	2.036	0.237	0.264
189	58	0.185	0.03	1.65	1.62	0.219	0.233	0.139	2.018	0.177	0.215
198	120	0.166	0.02	0.8	0.78	0.164	0.191	0.112	2.375	0.163	0.193
204	63	0.139	0.05	0.6	0.55	0.122	0.165	0.105	2.053	0.135	0.163
205	9	0.119	0.028	0.226	0.198	0.067	0.160	0.100	1.948	0.121	0.227
212	13	0.093	0.05	0.2	0.15	0.038	0.112	0.087	1.456	0.093	0.115
221	7	0.314	0.2	0.6	0.4	0.146	0.422	0.290	1.519	0.312	0.467

Appendix E Coal mines—Respirable Crystalline Silica (RCS)

Respirable Crystalline silica is better controlled in coal mines than total respirable coal mine dust, based on the OEL.

There are a large number of RCS exposure samples for coal mines over the last three years. Data before 2017 is not included.

The stone drivage SEG shows an average and LOG UCL above half the OEL and a UCL above the exposure limit. Very few stone drivage samples have been taken in 2019 and 2020.

This data set was found to have fewer errors and erroneous categorisations than the MMQ data, which is most likely a result of the increased emphasis on education for those collecting the samples and the greater focus of RSHQ on data verification and reporting in coal.

Table 76 shows the respirable crystalline silica exposures by year for all the coal mine types including coal processing, surface coal and underground coal. There were 27,776 samples taken over the 2017 to 2020 period including 3,078 samples for coal processing, 14,931 for surface coal and 9,767 for underground coal. The overall levels are all below half the OEL of 0.05 mg/m^3.

Table 76: RCS Exposure for Coal by SEG Group and Year

Mine Type by Year	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Coal Processing	3,078	0.007	0.001	0.19	0.189	0.010	0.007	0.005	2.323	0.007	0.007
2017	666	0.009	0.003	0.13	0.127	0.012	0.010	0.006	2.126	0.008	0.009
2018	785	0.009	0.001	0.19	0.189	0.013	0.010	0.006	2.284	0.008	0.009
2019	798	0.006	0.001	0.065	0.064	0.007	0.006	0.004	2.266	0.006	0.006
2020	829	0.005	0.001	0.156	0.155	0.008	0.005	0.003	2.177	0.004	0.004
Surface Coal	14,931	0.011	0.001	1.1	1.099	0.024	0.012	0.006	2.750	0.010	0.010
2017	3,008	0.016	0.001	1.1	1.099	0.035	0.017	0.009	2.435	0.014	0.014
2018	3,823	0.014	0.001	0.5	0.499	0.023	0.014	0.008	2.576	0.013	0.013
2019	4,104	0.010	0.001	0.462	0.461	0.017	0.010	0.006	2.681	0.009	0.010
2020	3,996	0.007	0.001	0.759	0.758	0.017	0.007	0.004	2.635	0.006	0.006
Underground Coal	9,767	0.009	0.001	1.7	1.699	0.032	0.010	0.005	2.619	0.007	0.007
2017	2,659	0.010	0.003	1.5	1.497	0.032	0.011	0.006	2.226	0.008	0.008
2018	2,626	0.012	0.001	1.7	1.699	0.048	0.013	0.005	2.613	0.008	0.008
2019	2,489	0.007	0.001	0.29	0.289	0.014	0.008	0.004	2.750	0.007	0.007
2020	1,993	0.007	0.001	0.42	0.419	0.017	0.007	0.003	2.639	0.005	0.005
Total	**27,776**	**0.010**	**0.001**	**1.7**	**1.699**	**0.026**	**0.010**	**0.005**	**2.689**	**0.009**	**0.009**

Figure 38 and Figure 39 show the movement of the average (normal parametric mean), geometric mean and Log UCL (lognormal parametric 95% UCL) over the 2017 to 2020 period. All parameters show a decrease in exposure levels over the period.

Figure 37: RCS Exposure for Coal Processing SEGs by Year

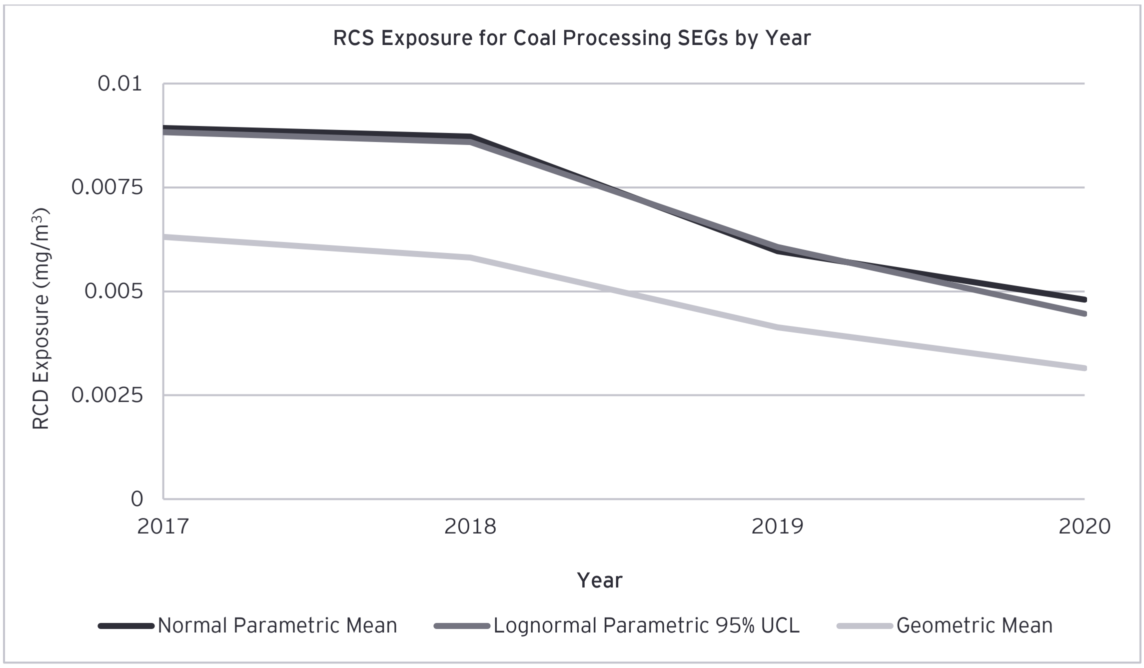


Figure 38: RCS Exposure for Surface Coal SEGs by Year

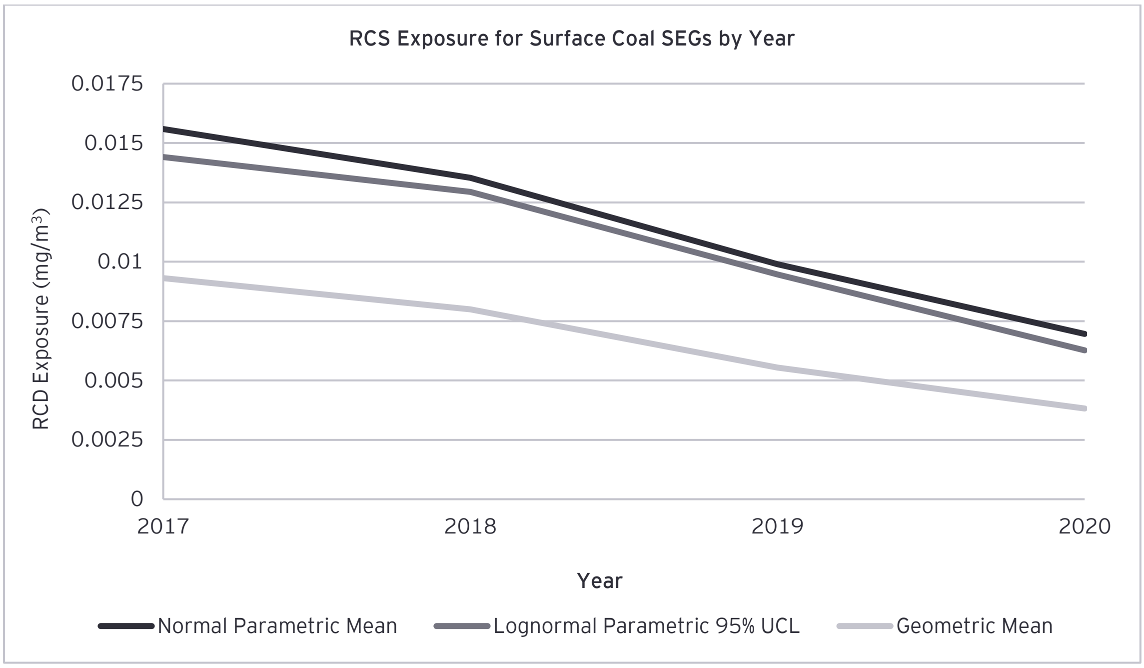


Figure 39: RCS Exposure for Underground Coal SEGs by Year

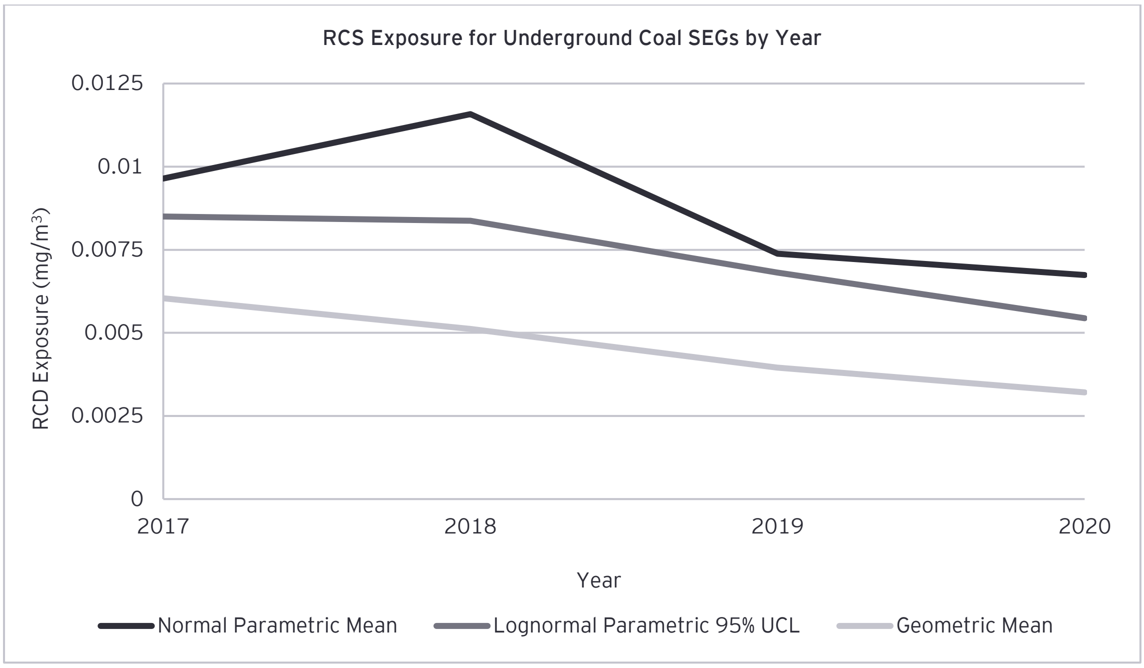


Table 77 and Figure 40 show the RCS exposures for underground coal by SEG. The highest exposure by far is the stone drivage SEG with an average of 0.038 mg/m^3. The UCL for the stone drivage SEG is over the OEL and the Log UCL is over half the OEL. The only other SEG with a parameter above half the OEL is the Log UCL for boilermaker (surface). Overall the RCS levels are sufficiently below half the OEL.

Table 77: RCS Exposure for Underground Coal by SEG

Underground Coal SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Administration	24	0.005	0.002	0.044	0.042	0.009	0.008	0.004	2.035	0.004	0.006
Belt Splicers	96	0.006	0.002	0.11	0.108	0.011	0.008	0.004	1.992	0.005	0.006
Boilermaker (Surface)	7	0.013	0.005	0.047	0.042	0.015	0.025	0.009	2.364	0.012	0.041
Control Room Operator	33	0.003	0.002	0.006	0.004	0.001	0.003	0.003	1.361	0.003	0.003
Development Production	2221	0.012	0.001	1.7	1.699	0.056	0.014	0.005	2.847	0.009	0.009
ERZ Controller	711	0.006	0.001	0.19	0.189	0.014	0.007	0.003	2.331	0.005	0.005
Gas Drainage	214	0.009	0.002	0.18	0.178	0.022	0.012	0.005	2.637	0.007	0.008
Longwall Moves	588	0.006	0.001	0.067	0.066	0.007	0.006	0.004	2.282	0.006	0.006
Longwall Production	1934	0.012	0.001	0.32	0.319	0.020	0.012	0.006	2.780	0.011	0.011
Outbye Construction / Infrastru	640	0.006	0.001	0.068	0.067	0.008	0.006	0.004	2.185	0.005	0.005
Outbye Supplies	39	0.006	0.002	0.03	0.028	0.007	0.008	0.004	2.202	0.006	0.008
Production support / bullgang	829	0.006	0.001	0.29	0.289	0.014	0.007	0.004	2.337	0.005	0.005
Resin Worker	15	0.003	0.002	0.007	0.005	0.001	0.004	0.003	1.453	0.003	0.004
Returns	24	0.006	0.002	0.018	0.016	0.005	0.007	0.004	2.074	0.005	0.008
Second Support	517	0.005	0.001	0.076	0.075	0.007	0.006	0.003	2.260	0.005	0.005
Shift Co-ordinator / Manageme	109	0.004	0.001	0.032	0.031	0.004	0.004	0.003	1.835	0.004	0.004
Stone Drivage	144	0.038	0.002	0.78	0.778	0.098	0.052	0.011	3.814	0.027	0.036
Surface Maintenance	132	0.003	0.001	0.02	0.019	0.002	0.003	0.003	1.662	0.003	0.003
Surface other	281	0.009	0.001	0.1	0.099	0.013	0.010	0.005	2.791	0.008	0.009
Underground Maintenance	690	0.006	0.001	0.11	0.109	0.009	0.006	0.004	2.240	0.005	0.006
Underground other	159	0.004	0.002	0.038	0.036	0.005	0.005	0.003	1.813	0.004	0.004
VCD Installer	360	0.007	0.001	0.089	0.088	0.009	0.008	0.005	2.310	0.006	0.007

Figure 40: Average RCS Exposure for Underground Coal by SEG

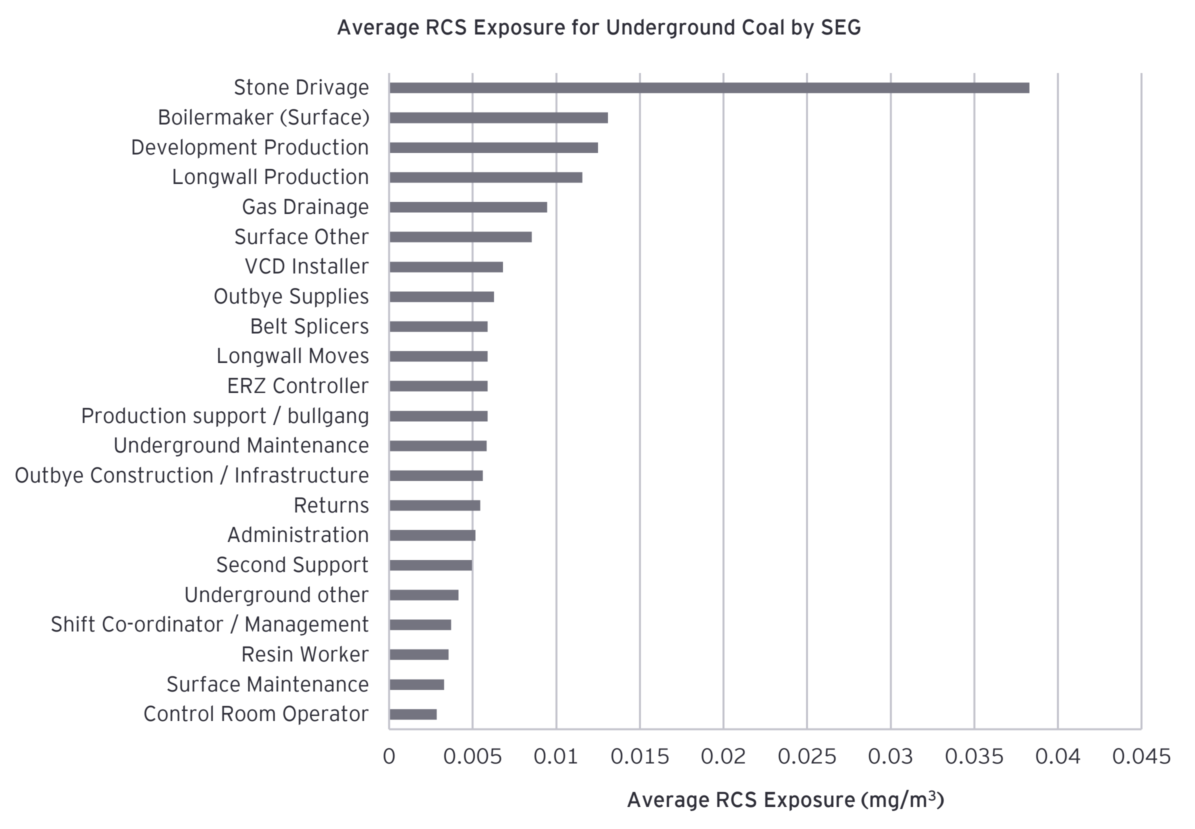


Table 78 and Figure 41 show the RCS exposures for surface coal. The exploration drillers have the highest average exposure. The dozer push SEG has a UCL have the OEL and the pump crew has a Log UCL above the OEL.

Table 78: RCS Exposure for Surface Coal by SEG

Surface Coal SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Administration	112	0.005	0.001	0.03	0.029	0.005	0.006	0.004	1.990	0.005	0.005
Blast crew	1426	0.016	0.001	0.205	0.204	0.019	0.016	0.010	2.723	0.016	0.017
Blast hole drillers	1019	0.014	0.001	0.18	0.179	0.018	0.015	0.008	2.884	0.014	0.015
Boilermaker	195	0.007	0.001	0.11	0.109	0.012	0.008	0.004	2.476	0.006	0.007
Coal removal	1497	0.008	0.001	0.13	0.129	0.009	0.008	0.005	2.394	0.008	0.008
Dozer Push	2	0.009	0.001	0.016	0.015	0.011	0.056	0.004	7.103	0.008	-
Dragline	768	0.015	0.001	0.5	0.499	0.027	0.016	0.008	3.034	0.014	0.015
Emergency response personnel	15	0.003	0.002	0.01	0.008	0.002	0.004	0.003	1.646	0.003	0.004
Exploration drillers	513	0.018	0.001	0.23	0.229	0.028	0.020	0.008	3.359	0.017	0.020
Field Maintenance	1554	0.014	0.001	1.1	1.099	0.046	0.015	0.006	2.815	0.010	0.011
Open cut inspection services	355	0.006	0.001	0.08	0.079	0.008	0.007	0.004	2.471	0.006	0.007
Open cut other	1713	0.011	0.001	0.759	0.758	0.027	0.012	0.006	2.799	0.010	0.010
Pre-strip and overburden remo	1761	0.011	0.001	0.151	0.15	0.013	0.011	0.007	2.543	0.011	0.011
Production Dozing	401	0.011	0.001	0.18	0.179	0.014	0.012	0.007	2.600	0.011	0.012
Pump Crew	10	0.010	0.001	0.038	0.037	0.014	0.018	0.004	3.932	0.010	0.067
Road maintenance	718	0.009	0.001	0.17	0.169	0.013	0.009	0.005	2.476	0.008	0.009
Service crew	503	0.011	0.001	0.462	0.461	0.025	0.012	0.006	2.499	0.010	0.010
Tech services	466	0.006	0.001	0.114	0.113	0.009	0.007	0.004	2.292	0.006	0.006
Tyre fitters	387	0.012	0.001	0.2	0.199	0.020	0.014	0.006	2.949	0.012	0.013
Warehousing	196	0.010	0.001	0.08	0.079	0.013	0.012	0.006	2.613	0.010	0.011
Workshop	1320	0.008	0.001	0.43	0.429	0.023	0.009	0.004	2.489	0.007	0.007

Figure 41: Average RCS Exposure for Surface Coal by SEG

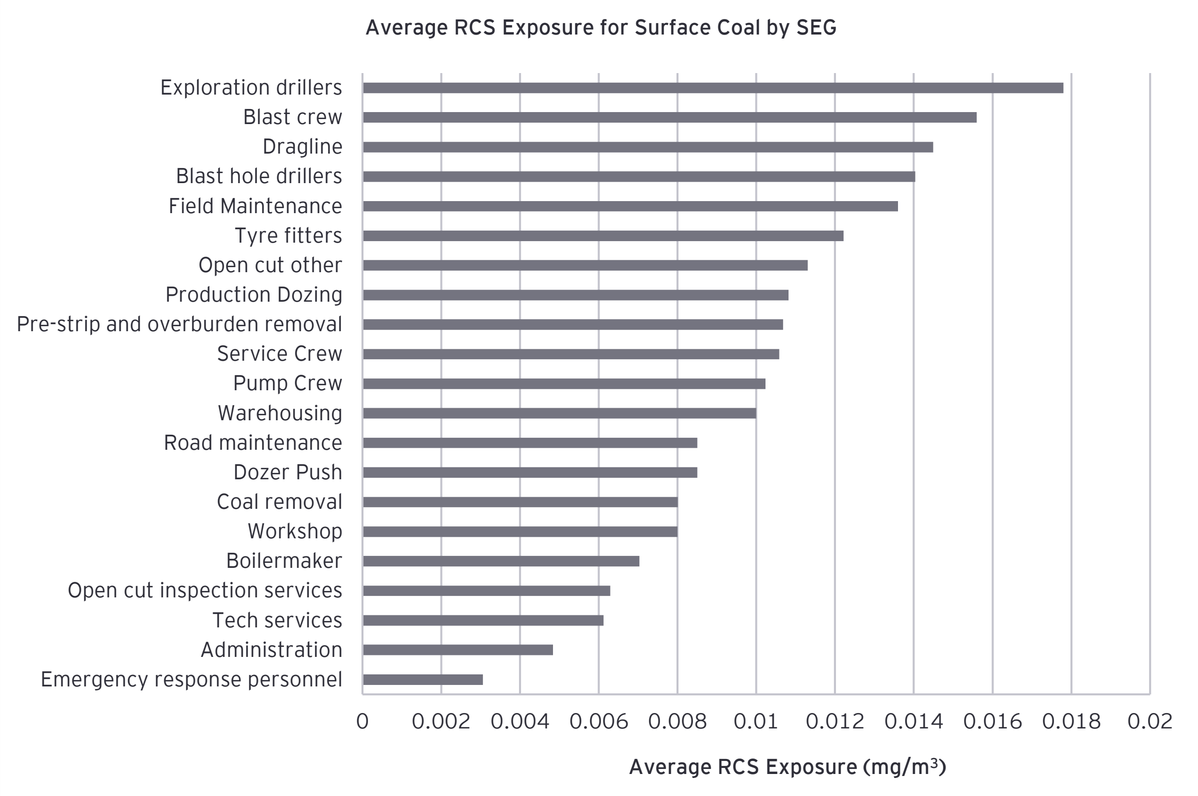


Table 79 and Figure 42 show the RCS exposure for the coal processing SEGs. The CHPP laboratory had the highest average exposure at 0.01 for 670 samples. All the parameters are below half the OEL.

Table 79: RCS Exposure for Coal Processing by SEG

Coal Processing SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Belt Splicers	28	0.006	0.002	0.034	0.032	0.007	0.008	0.004	2.162	0.006	0.008
CHPP dozer	167	0.007	0.001	0.09	0.089	0.009	0.008	0.004	2.292	0.006	0.007
CHPP laboratory	670	0.010	0.001	0.19	0.189	0.016	0.011	0.006	2.601	0.009	0.010
CHPP maintenance	720	0.006	0.001	0.052	0.051	0.006	0.006	0.004	2.142	0.006	0.006
CHPP other	167	0.006	0.001	0.038	0.037	0.007	0.007	0.004	2.390	0.006	0.007
CHPP production	1326	0.006	0.001	0.11	0.109	0.008	0.007	0.004	2.222	0.006	0.006

Figure 42: Average RCS Exposure for Coal Processing by SEG

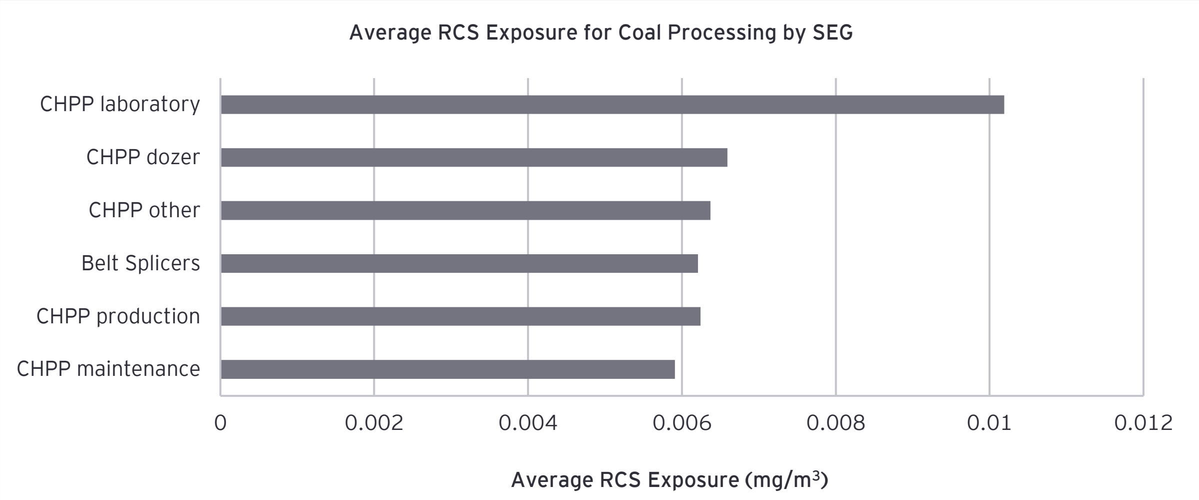
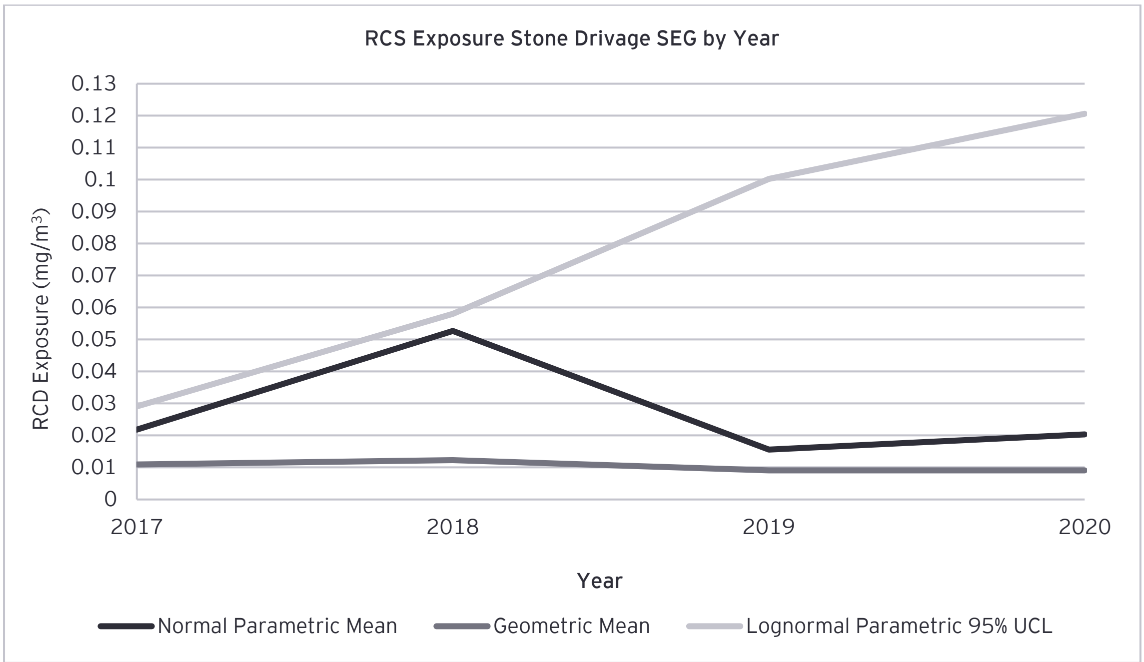


Table 80 and Figure 43 show the RCS exposure for the underground stone drivage SEG by year. The average was above the OEL in 2018. All of the UCL and Log UCL are over half the OEL. This show that the RCS exposure for this SEG is not well controlled and has not improved. There have been less samples taken in 2019 and 2020 than in previous years.

Table 80: RCS Exposure for Stone Drivage SEG by Year

Stone Drivage	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2017	47	0.022	0.003	0.29	0.287	0.044	0.033	0.011	2.953	0.019	0.029
2018	79	0.052	0.002	0.78	0.778	0.127	0.076	0.012	4.466	0.036	0.059
2019	8	0.016	0.002	0.063	0.061	0.020	0.029	0.008	3.319	0.015	0.100
2020	10	0.020	0.002	0.1	0.098	0.030	0.038	0.009	3.787	0.019	0.120

Figure 43: RCS Exposure for Stone Drivage SEG by Year



Appendix F Diesel data analysis

Data analysis was performed on the RSHQ Personal Diesel results database including 10,589 samples collected between 2002 and 2020. This analysis was performed by calendar year.

Recommendations

Diesel particulate matter was declared a group 1 carcinogen by IARC in 2012, when IARC found sufficient evidence linking exposure to diesel exhaust to increased risk of lung cancer. Instead of a recommended limit, RSHQ should specify an Occupational Exposure limit should be set for DPM. NSW specifies a limit of 0.1 mg/m^3 (measured as sub-micron elemental carbon).

A standard shift adjustment methodology should be set to calculate exceedances. Upon review of the data it was noted that reductions factors are inconsistently applied between mines and consultants. The review found that at for several mines applied reduction factors to samples taken in some months and not others.

The data was analysed by several different parameters including year, Similar Exposure Group (SEG) and mine number. The SEGs with the highest average DPM concentration are listed in Table 81 below. The top five SEGs all have average concentrations above half of the recommend OEL of 0.1 mg/m^3.

Table 81: DPM Exposure by SEG

Diesel Particulate Matter	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Longwall Moves	1249	0.074	0.001	0.956	0.955	0.078	0.078	0.043	3.504	0.094	0.102
Outbye Supplies	579	0.061	0.001	0.800	0.799	0.066	0.065	0.038	3.013	0.069	0.077
Development Production	2485	0.057	0.001	0.960	0.959	0.050	0.058	0.037	3.000	0.067	0.070
Returns	18	0.051	0.007	0.160	0.153	0.035	0.066	0.041	2.100	0.053	0.081
Stone Drivage	82	0.050	0.006	0.240	0.234	0.047	0.059	0.035	2.264	0.049	0.060
Longwall Production	1015	0.042	0.001	0.270	0.269	0.037	0.043	0.027	2.843	0.047	0.051
VCD Installer	380	0.040	0.001	0.170	0.169	0.033	0.043	0.027	2.620	0.043	0.048
Second Support	666	0.039	0.001	0.245	0.244	0.038	0.041	0.022	3.526	0.047	0.053
Gas Drainage	111	0.038	0.001	0.120	0.119	0.024	0.042	0.030	2.248	0.041	0.048
Resin Worker	16	0.035	0.011	0.069	0.058	0.018	0.042	0.031	1.710	0.035	0.047
Underground Maintenance	1130	0.034	0.001	0.900	0.899	0.051	0.036	0.016	3.780	0.040	0.044
Production support / bullgang	688	0.033	0.001	0.330	0.329	0.032	0.035	0.020	3.145	0.038	0.042
Outbye Construction / Infrastructure	871	0.031	0.001	0.280	0.279	0.031	0.032	0.018	3.168	0.035	0.038
ERZ Controller	770	0.028	0.001	0.259	0.258	0.030	0.030	0.016	3.215	0.032	0.035
Shift Co-ordinator / Management	67	0.024	0.001	0.290	0.289	0.045	0.033	0.007	4.902	0.023	0.042
Belt Splicers	87	0.024	0.002	0.110	0.108	0.021	0.027	0.016	2.453	0.024	0.030
Underground other	170	0.021	0.001	0.110	0.109	0.019	0.023	0.014	2.737	0.022	0.027
Tech services	4	0.015	0.002	0.042	0.040	0.019	0.037	0.008	3.755	0.014	14.759
Administration	1	0.006	0.006	0.006	0.000	-	-	0.006	-	-	-
Surface Maintenance	143	0.006	0.001	0.095	0.094	0.009	0.007	0.004	2.310	0.006	0.006
Exploration drillers	3	0.005	0.005	0.005	0.000	0.000	0.005	0.005	1.000	0.005	0.006
Surface other	21	0.002	0.001	0.005	0.004	0.002	0.003	0.002	2.133	0.002	0.004
CHPP dozer	7	0.002	0.001	0.006	0.005	0.002	0.004	0.002	2.191	0.002	0.006
CHPP other	14	0.002	0.001	0.005	0.004	0.001	0.002	0.001	1.635	0.002	0.002
CHPP maintenance	6	0.002	0.001	0.003	0.002	0.001	0.002	0.001	1.616	0.001	0.003
CHPP production	6	0.001	0.001	0.002	0.001	0.000	0.002	0.001	1.327	0.001	0.002
All Diesel Data	10589	0.045	0.001	0.960	0.959	0.051	0.046	0.025	3.476	0.055	0.056

Figure 44 shows the trend over time of the average exposure of the six SEGs. Overall the Longwall Moves, Outbye Supplies, Development Production and Longwall Production SEGs show a downward trend which indicates a reduction in the average exposure over the years. The average of the Returns and Stone Drivage SEGs increased over the 2017 to 2019 period.

Figure 44: SEGs with Highest Average DPM Exposure by Year

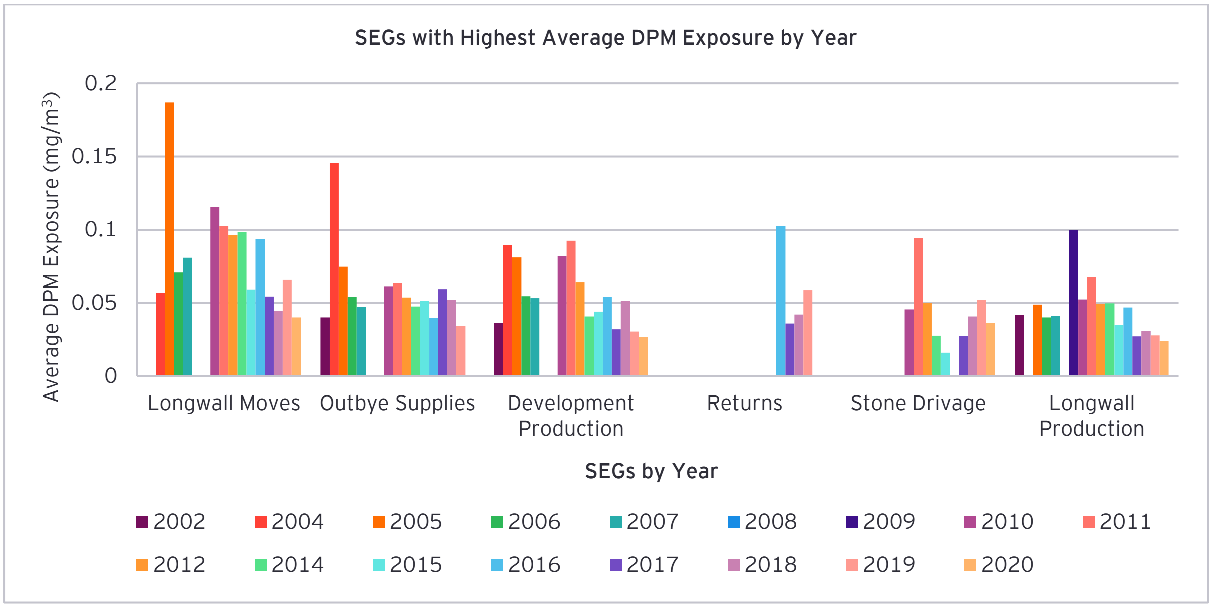


Table 82: DPM Exposure for Longwall Moves SEG

Longwall Moves SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2004	6	0.057	0.03	0.100	0.07	0.024	0.077	0.053	1.507	0.057	0.089
2005	32	0.187	0.03	0.400	0.37	0.088	0.213	0.166	1.683	0.190	0.228
2006	46	0.071	0.001	0.200	0.199	0.048	0.083	0.043	4.221	0.116	0.221
2007	21	0.081	0.01	0.250	0.24	0.071	0.108	0.056	2.457	0.082	0.136
2010	122	0.115	0.001	0.956	0.955	0.149	0.138	0.061	3.629	0.138	0.186
2011	56	0.103	0.002	0.423	0.421	0.078	0.120	0.076	2.416	0.111	0.145
2012	63	0.096	0.011	0.260	0.249	0.057	0.108	0.080	1.911	0.099	0.117
2014	66	0.098	0.003	0.470	0.467	0.081	0.115	0.071	2.511	0.107	0.139
2015	76	0.059	0.002	0.200	0.198	0.044	0.067	0.045	2.251	0.062	0.075
2016	180	0.094	0.002	0.420	0.418	0.070	0.102	0.071	2.208	0.097	0.110
2017	166	0.054	0.001	0.250	0.249	0.051	0.061	0.034	2.882	0.059	0.072
2018	174	0.045	0.001	0.180	0.179	0.036	0.049	0.030	2.767	0.051	0.060
2019	60	0.066	0.002	0.210	0.208	0.048	0.076	0.046	2.751	0.075	0.103
2020	181	0.040	0.001	0.270	0.269	0.052	0.046	0.014	5.354	0.058	0.084
Total	1249	0.074	0.001	0.956	0.955	0.078	0.078	0.043	3.504	0.094	0.102

Figure 45 shows the average of the Longwall Move SEG for each mine by year. This data shows a general downward trend in exposure levels. In 2019 and 2020 there were two and three mines respectively averaged above half the exposure standard.

Figure 45: Average of Longwall Move SEG by Mine and Year

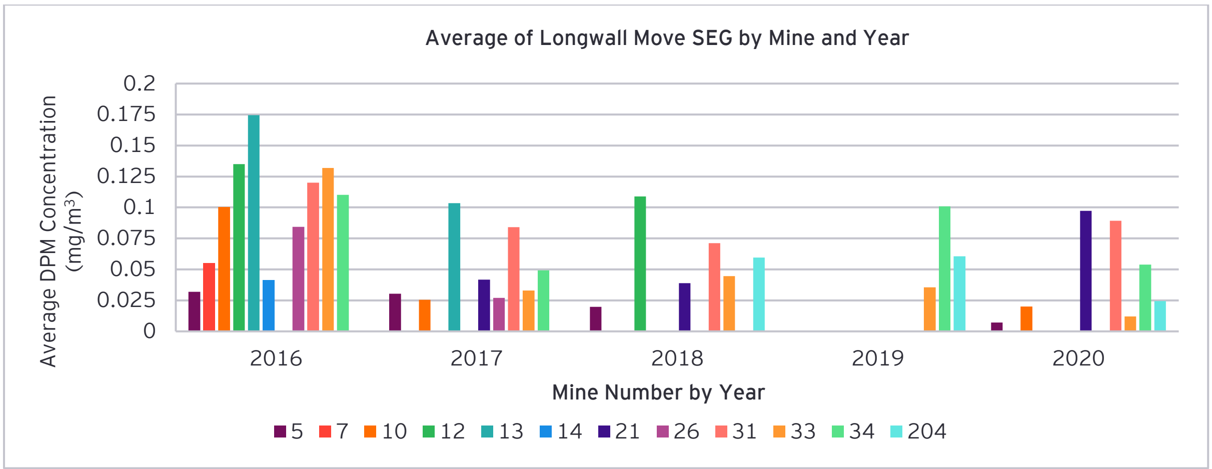


Table 83: DPM Exposure for Development Production SEG by Year

Development Production SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2002	10	0.036	0.019	0.080	0.061	0.019	0.047	0.032	1.621	0.036	0.051
2004	14	0.089	0.04	0.170	0.13	0.042	0.109	0.081	1.592	0.089	0.117
2005	132	0.081	0.01	0.280	0.27	0.052	0.089	0.065	2.065	0.084	0.095
2006	83	0.055	0.001	0.140	0.139	0.030	0.060	0.042	2.535	0.065	0.082
2007	59	0.053	0.001	0.190	0.189	0.045	0.063	0.031	3.582	0.069	0.108
2010	209	0.082	0.001	0.286	0.285	0.057	0.089	0.057	2.959	0.103	0.122
2011	296	0.092	0.003	0.332	0.329	0.054	0.098	0.077	1.960	0.096	0.104
2012	327	0.064	0.001	0.181	0.18	0.036	0.067	0.051	2.182	0.070	0.076
2014	215	0.041	0.002	0.570	0.568	0.046	0.046	0.028	2.516	0.043	0.049
2015	127	0.044	0.003	0.120	0.117	0.028	0.048	0.034	2.226	0.047	0.054
2016	255	0.054	0.003	0.300	0.297	0.044	0.059	0.039	2.397	0.057	0.064
2017	266	0.032	0.001	0.140	0.139	0.027	0.035	0.018	3.670	0.042	0.051
2018	190	0.051	0.001	0.960	0.959	0.076	0.061	0.031	3.126	0.059	0.072
2019	183	0.030	0.002	0.200	0.198	0.030	0.034	0.020	2.704	0.032	0.038
2020	119	0.027	0.001	0.180	0.179	0.031	0.031	0.013	3.773	0.032	0.044
Total	2485	0.057	0.001	0.960	0.959	0.050	0.058	0.037	3.000	0.067	0.070

Error! Not a valid bookmark self-reference. shows the average of the Development Production SEG for each mine by year. This data shows a general downward trend in exposure levels. In 2016 and 2018 there were six mines who averaged above half the exposure standard, while in 2019 and 2020 this has been reduced to two mines.

Figure 46: Average of Development Production SEG by Mine and Year

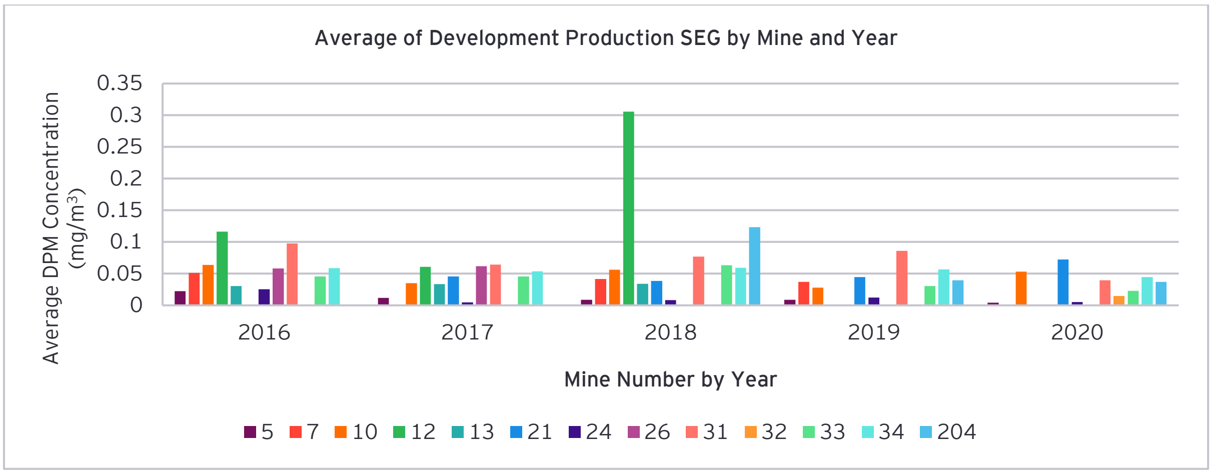


Figure 47 shows the average of the Longwall Production SEG for each mine by year. Three mines show an upward trend while the rest show a reduction over time in average exposure.

Table 84: DPM Data for Longwall Production SEG by Year

Longwall Production SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2002	3	0.042	0.04	0.043	0.003	0.002	0.044	0.042	1.038	0.042	0.044
2005	21	0.049	0.005	0.120	0.115	0.039	0.063	0.033	2.690	0.052	0.094
2006	20	0.040	0.01	0.130	0.12	0.032	0.052	0.030	2.262	0.040	0.064
2007	20	0.041	0.006	0.110	0.104	0.026	0.051	0.032	2.237	0.043	0.067
2009	5	0.100	0.055	0.165	0.11	0.042	0.140	0.093	1.513	0.100	0.177
2010	115	0.052	0.003	0.258	0.255	0.053	0.060	0.036	2.373	0.052	0.062
2011	91	0.067	0.011	0.220	0.209	0.046	0.075	0.055	1.889	0.068	0.077
2012	105	0.049	0.001	0.210	0.209	0.039	0.056	0.035	2.702	0.056	0.070
2014	69	0.050	0.005	0.270	0.265	0.041	0.058	0.034	2.625	0.054	0.071
2015	65	0.035	0.003	0.130	0.127	0.023	0.040	0.029	1.951	0.036	0.043
2016	106	0.047	0.003	0.140	0.137	0.027	0.051	0.038	2.130	0.050	0.058
2017	137	0.027	0.001	0.076	0.075	0.019	0.030	0.019	2.655	0.031	0.037
2018	99	0.031	0.001	0.094	0.093	0.023	0.035	0.021	2.825	0.036	0.046
2019	85	0.028	0.001	0.110	0.109	0.027	0.033	0.015	3.394	0.032	0.045
2020	74	0.024	0.001	0.170	0.169	0.029	0.030	0.012	3.922	0.029	0.045
Total	1015	0.042	0.001	0.270	0.269	0.037	0.043	0.027	2.843	0.047	0.051

Figure 47: Average of Longwall Production SEG by Mine and Year

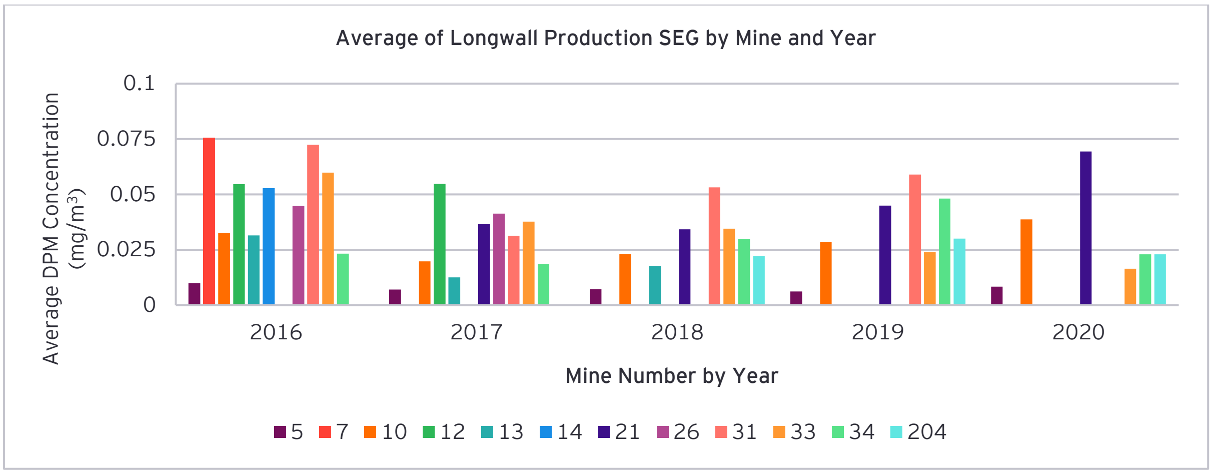


Table 85: DPM Exposure for Outbye Supplies SEG by Year

Outbye Supplies SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2002	1	0.040	0.04	0.040	0	-	-	0.040	-	-	-
2004	21	0.145	0.01	0.800	0.79	0.183	0.214	0.083	2.972	0.144	0.287
2005	72	0.075	0.01	0.340	0.33	0.061	0.087	0.055	2.275	0.077	0.095
2006	45	0.054	0.005	0.140	0.135	0.032	0.062	0.043	2.121	0.057	0.073
2007	29	0.047	0.001	0.120	0.119	0.035	0.058	0.028	3.652	0.063	0.130
2010	93	0.061	0.001	0.250	0.249	0.059	0.071	0.035	3.548	0.077	0.109
2011	90	0.063	0.001	0.418	0.417	0.066	0.075	0.039	3.230	0.076	0.104
2012	130	0.054	0.003	0.560	0.557	0.057	0.062	0.036	2.754	0.059	0.072
2014	32	0.047	0.003	0.190	0.187	0.048	0.062	0.024	3.922	0.057	0.121
2015	19	0.051	0.005	0.218	0.213	0.057	0.074	0.031	2.821	0.051	0.101
2016	25	0.040	0.003	0.180	0.177	0.042	0.054	0.025	2.688	0.040	0.068
2017	9	0.059	0.035	0.130	0.095	0.028	0.077	0.055	1.464	0.059	0.078
2018	3	0.052	0.047	0.061	0.014	0.008	0.065	0.052	1.156	0.052	0.071
2019	10	0.034	0.003	0.110	0.107	0.032	0.053	0.021	3.065	0.036	0.138
Total	579	0.061	0.001	0.800	0.799	0.066	0.065	0.038	3.013	0.069	0.077

Table 86: DPM Exposure for Returns SEG by Year

Returns SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2016	2	0.103	0.045	0.160	0.115	0.081	0.466	0.085	2.452	0.102	-
2017	6	0.036	0.014	0.068	0.054	0.020	0.052	0.031	1.767	0.036	0.076
2018	5	0.042	0.021	0.068	0.047	0.020	0.061	0.038	1.658	0.042	0.092
2019	5	0.059	0.007	0.084	0.077	0.031	0.088	0.044	2.847	0.067	1.118
Total	18	0.051	0.007	0.160	0.153	0.035	0.066	0.041	2.100	0.053	0.081

Table 87: DPM Exposure for Stone Drivage SEG by Year

Stone Drivage SEG	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
2010	4	0.046	0.021	0.095	0.074	0.033	0.085	0.038	1.897	0.045	0.245
2011	19	0.094	0.007	0.240	0.233	0.075	0.124	0.059	3.139	0.108	0.240
2012	1	0.050	0.05	0.050	0	-	-	0.050	-	-	-
2014	5	0.028	0.018	0.060	0.042	0.018	0.045	0.024	1.657	0.027	0.059
2015	1	0.016	0.016	0.016	0	-	-	0.016	-	-	-
2017	17	0.027	0.006	0.059	0.053	0.015	0.034	0.023	1.882	0.028	0.040
2018	21	0.041	0.01	0.096	0.086	0.029	0.052	0.032	2.015	0.041	0.058
2019	6	0.052	0.024	0.069	0.045	0.019	0.067	0.048	1.544	0.052	0.086
2020	8	0.036	0.02	0.070	0.05	0.015	0.046	0.034	1.437	0.036	0.048
Total	82	0.050	0.006	0.240	0.234	0.047	0.059	0.035	2.264	0.049	0.060

Appendix G Mineral mines and quarries—Respirable Crystalline Silica (RCS)

Respirable crystalline silica exposure is a significant issue for mineral mines and quarries. The average exposures are high for the minerals processing, exploration, and surface alluvial gold mine types. A number of the SEGs in all mine types are not well controlled as evidenced by the amber and red lights in the tables.

It is important to recognise the limitations of analysing exposure data from mineral mines and quarries. A large variability in the size and function of operations within the mineral mines and quarries sector make comparative assessments challenging. Additionally, workers tend to rotate between roles within the same operation, meaning SEGs are difficult to apply. This is evidenced through the high Geometric Standard Deviations reported against mine types and SEGs. The complexity of the work environment should be taken into account when reviewing this analysis.

Very few samples are in the data set for quarry-group, surface or underground gemstone, surface alluvial gold, exploration and dredging operations. This makes it difficult to accurately estimate the exposures for these groups.

Some mine types have large numbers of samples in "N/A" or "not otherwise classified" SEG categories. The SEGs should be reviewed for adequacy and the data coming in should be reviewed for appropriate categorisation. Many of the N/A or NOC classifications clearly belong in another SEG group based on primary activity listed.

The mineral processing mine type should be reviewed for the applicability of all SEGs attributed to this mine type. Some clearly look to be mining activities and not mineral processing.

Respirable crystalline silica exposures were analysed for the RSHQ Mineral Mines and Quarries data set from 1 July 2017 to 31 December 2020. There were 7,340 samples taken during this time. Respirable crystalline silica is of concern for the MMQ population. Minerals Processing, and exploration have average and 95% UCL levels above half the OEL of 0.05 mg/m^3. The three samples for surface alluvial gold have both the average, UCL and Log UCL above the OEL. Many of the mine types have a small number of samples which may not properly show the full range of exposures being experienced.

Table 88: Mineral Mines and Quarries RCS Exposure by Mine Type

RCS by Mine Type	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Metalliferous - Minerals Processing	471	0.029	0.001	2.500	2.499	0.175	0.043	0.005	3.509	0.011	0.013
Metalliferous - Quarry	2661	0.021	0.002	0.840	0.838	0.055	0.022	0.009	2.974	0.016	0.016
Metalliferous Mine - Dredging Operation	65	0.016	0.002	0.120	0.118	0.019	0.020	0.010	2.608	0.016	0.021
Metalliferous Mine - Exploration	54	0.028	0.002	0.280	0.278	0.052	0.040	0.009	4.261	0.025	0.045
Metalliferous Mine - Surface	1436	0.021	0.001	0.880	0.879	0.059	0.023	0.007	3.417	0.015	0.016
Metalliferous Mine - Surface Alluvial Gold	3	0.060	0.01	0.140	0.13	0.070	0.178	0.035	3.765	0.058	918511.547
Metalliferous Mine - Surface or Underground Gemstone	39	0.018	0.001	0.070	0.069	0.016	0.022	0.013	2.334	0.018	0.025
Metalliferous Mine - Underground	2572	0.021	0.001	2.500	2.499	0.068	0.024	0.008	3.487	0.018	0.020
Metalliferous Quarry - Group	39	0.012	0.003	0.061	0.058	0.014	0.016	0.008	2.275	0.011	0.015
All MMQ Data	7340	0.021	0.001	2.500	2.499	0.073	0.023	0.008	3.300	0.016	0.017

Table 89 and Figure 48 show the RCS exposures for the surface metalliferous SEGs. There is one shotcrete sample with an exposure of 0.39 mg/m^3 which is significantly over the OEL. Shotcreting should be reviewed for appropriate RPE selection. There are 4 other SEGs with an average above the OEL and the classification and reverse circulation SEGs also have a geometric mean above half the OEL. This results in SEGs having 10 UCLs and 14 Log UCLs over the OEL as well as 15 UCLs and 4 Log UCLs over half the OEL. This does not show that silica is well controlled in the sector.

Table 89: RCS Exposure for Surface Metalliferous Mines by SEG

Surface SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	50	0.059	0.001	0.530	0.529	0.090	0.080	0.021	4.778	0.068	0.139
Export/ship loading	4	0.002	0.002	0.003	0.001	0.000	0.003	0.002	1.225	0.002	0.003
Export/train-loading	2	0.010	0.010	0.010	0.000	0.000	0.010	0.010	1.000	0.010	-
Export/truck-loading	29	0.013	0.002	0.093	0.091	0.020	0.019	0.006	3.207	0.011	0.020
Processing/crushing	64	0.034	0.001	0.590	0.589	0.081	0.051	0.012	3.896	0.029	0.047
Processing/dewatering	5	0.004	0.003	0.006	0.003	0.001	0.005	0.003	1.363	0.004	0.005
Processing/dry processing/classification	19	0.083	0.003	0.533	0.530	0.131	0.136	0.034	4.218	0.087	0.289
Processing/dry processing/cutting	9	0.031	0.005	0.110	0.105	0.032	0.051	0.020	2.757	0.031	0.107
Processing/dry processing/screening	19	0.046	0.002	0.260	0.258	0.084	0.079	0.012	4.786	0.038	0.151
Processing/not otherwise classified	65	0.013	0.001	0.080	0.079	0.018	0.017	0.006	3.147	0.012	0.018
Processing/smelting	14	0.011	0.002	0.058	0.056	0.018	0.019	0.005	3.053	0.009	0.023
Processing/technical/laboratory/analyst	22	0.023	0.002	0.150	0.148	0.037	0.036	0.008	4.031	0.020	0.056
Processing/technical/laboratory/sample prep	63	0.033	0.001	0.270	0.269	0.048	0.043	0.014	3.908	0.035	0.057
Processing/technical/science and engineering	22	0.052	0.002	0.620	0.618	0.151	0.107	0.007	4.841	0.022	0.079
Processing/wet processing/carbon-in-pulp	3	0.007	0.002	0.010	0.008	0.005	0.015	0.006	2.533	0.008	24.975
Processing/wet processing/cutting	25	0.029	0.002	0.230	0.228	0.048	0.046	0.012	4.020	0.028	0.071
Processing/wet processing/electro-winning	2	0.005	0.003	0.007	0.004	0.003	0.018	0.005	1.821	0.005	-
Processing/wet processing/flotation	14	0.020	0.002	0.190	0.188	0.049	0.044	0.007	3.663	0.014	0.050
Processing/wet processing/heap leach	4	0.009	0.002	0.027	0.025	0.012	0.023	0.005	3.260	0.008	1.954
Processing/wet processing/screening	29	0.009	0.002	0.034	0.032	0.009	0.011	0.006	2.397	0.008	0.012
Processing/wet processing/solvent extraction	11	0.007	0.002	0.020	0.018	0.005	0.010	0.005	1.909	0.007	0.011
Support/administration	18	0.010	0.001	0.080	0.079	0.018	0.017	0.005	2.591	0.008	0.015
Support/cleaners	12	0.004	0.002	0.010	0.008	0.003	0.006	0.004	1.759	0.004	0.006
Support/construction/plant	5	0.010	0.002	0.040	0.038	0.017	0.026	0.005	3.375	0.008	0.346
Support/laundry	2	0.002	0.001	0.002	0.001	0.001	0.005	0.001	1.633	0.001	-
Support/logistics	32	0.023	0.002	0.210	0.208	0.050	0.038	0.007	3.841	0.017	0.035
Support/maintenance/boilermaker	20	0.006	0.001	0.014	0.013	0.005	0.008	0.005	2.313	0.006	0.010
Support/maintenance/electrical plant	35	0.005	0.001	0.017	0.016	0.004	0.006	0.003	2.046	0.004	0.006
Support/maintenance/fixed plant	131	0.020	0.001	0.390	0.389	0.043	0.026	0.008	3.562	0.017	0.023
Support/maintenance/mobile plant/breakdown	52	0.009	0.002	0.088	0.086	0.014	0.012	0.005	2.454	0.008	0.011
Support/maintenance/mobile plant/workshop	39	0.007	0.002	0.031	0.029	0.008	0.009	0.005	2.312	0.007	0.009
Support/maintenance/welder/field	8	0.012	0.003	0.060	0.057	0.020	0.025	0.006	2.885	0.010	0.046
Support/maintenance/welder/workshop	14	0.009	0.002	0.031	0.029	0.009	0.013	0.006	2.483	0.008	0.016
Support/not otherwise classified	32	0.014	0.001	0.210	0.209	0.038	0.025	0.005	3.279	0.009	0.017
Support/resource definition/surface rig/diamond	4	0.005	0.002	0.009	0.007	0.003	0.008	0.004	1.889	0.004	0.024
Support/resource definition/surface rig/reverse circula	10	0.126	0.005	0.700	0.695	0.221	0.255	0.028	7.001	0.126	5.588
Support/technical/field	37	0.035	0.002	0.320	0.318	0.071	0.055	0.011	4.079	0.029	0.059
Support/technical/office	22	0.008	0.002	0.039	0.037	0.009	0.012	0.005	2.261	0.007	0.011
Surface/development/blasting/charge up	28	0.016	0.002	0.105	0.103	0.023	0.023	0.009	2.747	0.014	0.023
Surface/development/blasting/drill	40	0.019	0.002	0.180	0.178	0.039	0.030	0.008	3.248	0.015	0.024
Surface/development/dozer	24	0.010	0.002	0.078	0.076	0.016	0.016	0.006	2.456	0.009	0.014
Surface/development/excavator	23	0.007	0.002	0.060	0.058	0.013	0.011	0.004	2.417	0.005	0.009
Surface/development/rubber tyred loader	15	0.010	0.001	0.070	0.069	0.017	0.018	0.005	2.931	0.008	0.020
Surface/development/scraper	2	0.018	0.005	0.030	0.025	0.018	0.096	0.012	3.550	0.017	-
Surface/development/truck	40	0.008	0.001	0.070	0.069	0.013	0.012	0.005	2.680	0.007	0.011
Surface/not otherwise classified	25	0.010	0.003	0.040	0.037	0.010	0.014	0.007	2.249	0.010	0.014
Surface/production/excavator	51	0.024	0.002	0.690	0.688	0.096	0.046	0.006	3.272	0.013	0.020
Surface/production/rubber tyred loader	55	0.007	0.002	0.053	0.051	0.009	0.009	0.005	2.027	0.007	0.008
Surface/production/train	7	0.025	0.010	0.050	0.040	0.016	0.036	0.021	1.915	0.025	0.053
Surface/production/truck	69	0.027	0.001	0.880	0.879	0.108	0.048	0.006	3.778	0.015	0.023
Surface/services/refuel	5	0.003	0.002	0.005	0.003	0.002	0.005	0.003	1.652	0.003	0.007
Surface/services/road maintenance	10	0.006	0.002	0.021	0.019	0.005	0.009	0.005	1.910	0.006	0.010
Surface/services/water cart	14	0.007	0.002	0.020	0.018	0.006	0.010	0.005	2.402	0.007	0.013
Surface/technical/supervisor	28	0.006	0.001	0.020	0.019	0.005	0.008	0.005	2.034	0.006	0.008
Surface/technical/technical	30	0.009	0.002	0.051	0.049	0.011	0.012	0.005	2.553	0.008	0.012
Underground/development/drill/ long hole	1	0.004	0.004	0.004	0.000	-	-	0.004	-	-	-
Underground/development/drill/jumbo	2	0.025	0.023	0.026	0.003	0.002	0.034	0.024	1.091	0.025	-
Underground/ground control/shotcrete	1	0.390	0.390	0.390	0.000	-	-	0.390	-	-	-
Underground/not otherwise classified	14	0.006	0.002	0.015	0.013	0.004	0.007	0.004	1.996	0.005	0.009
Underground/production/loader	2	0.006	0.002	0.010	0.008	0.006	0.031	0.004	3.121	0.006	-
Underground/production/truck	2	0.019	0.005	0.032	0.027	0.019	0.104	0.013	3.716	0.018	-

Figure 48: Average RCS Exposure for Surface Metalliferous Mines by SEG

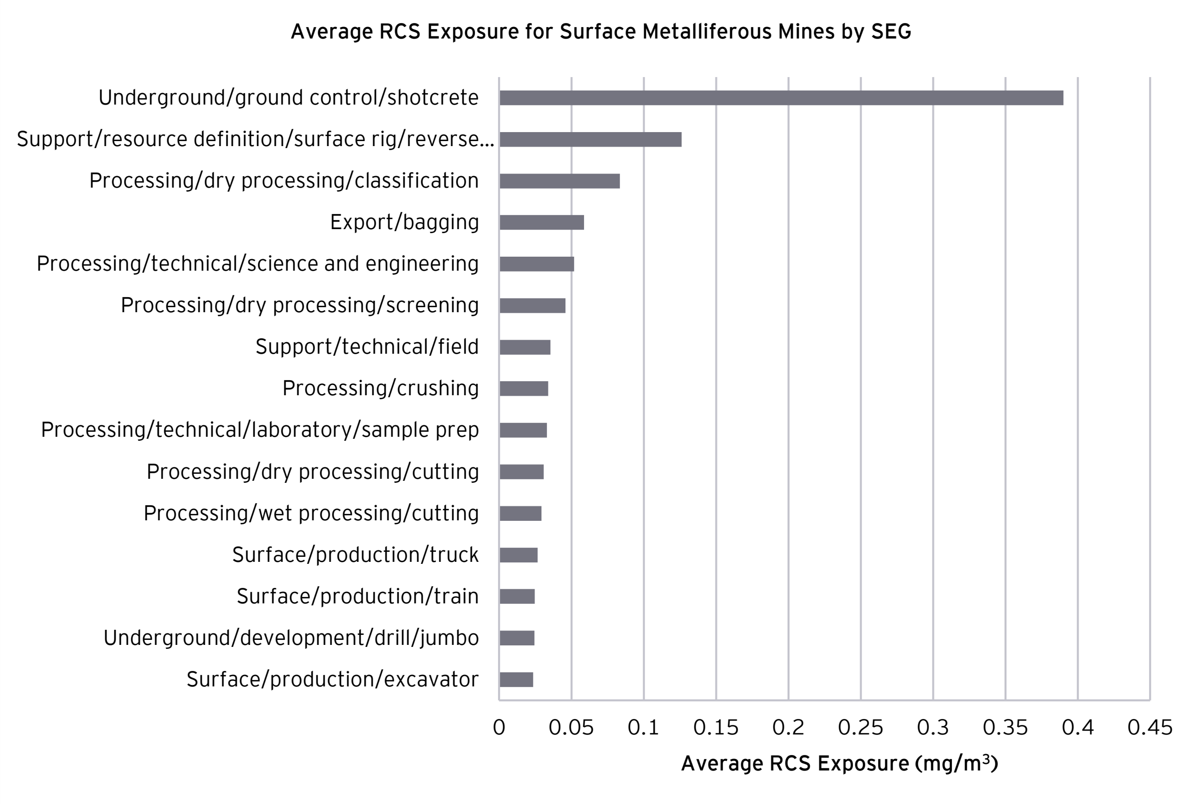


Table 90 and Figure 49 show the RCS exposures for the underground metalliferous mines. There are five SEGs with averages above the OEL and two of those SEGs also have geometric means above the OEL including field welders and blast drilling. The laboratory analysts have the highest average exposures including one that was 2.5 mg/m^3 which was double checked for accuracy. In the underground metalliferous SEGs there are 8 UCLs and 9 Log UCLs over the OEL as well as 10 UCLs and 13 Log UCLs over half the OEL. This does not show that silica is well controlled in the sector.

Table 90: RCS Exposure for Underground Metalliferous Mines by SEG

Underground Metalliferous Mine SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Export/ship loading	5	0.002	0.001	0.004	0.003	0.001	0.003	0.002	1.686	0.002	0.005
Export/truck-loading	13	0.003	0.001	0.004	0.003	0.001	0.003	0.002	1.455	0.003	0.003
N/A	201	0.013	0.003	0.084	0.081	0.015	0.014	0.007	2.744	0.012	0.014
Processing/crushing	104	0.033	0.001	0.274	0.273	0.039	0.039	0.017	3.598	0.038	0.053
Processing/dewatering	12	0.005	0.002	0.018	0.016	0.005	0.007	0.004	1.929	0.004	0.007
Processing/dry processing/classification	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Processing/dry processing/screening	23	0.022	0.002	0.079	0.077	0.020	0.030	0.016	2.528	0.023	0.039
Processing/not otherwise classified	55	0.009	0.001	0.067	0.066	0.012	0.012	0.005	2.663	0.008	0.011
Processing/technical/laboratory/analyst	14	0.243	0.002	2.500	2.498	0.670	0.560	0.015	9.685	0.127	5.285
Processing/technical/laboratory/sample prep	46	0.041	0.001	0.570	0.569	0.109	0.068	0.009	4.646	0.028	0.057
Processing/technical/science and engineering	13	0.003	0.001	0.007	0.006	0.002	0.004	0.003	1.776	0.003	0.005
Processing/wet processing/carbon-in-pulp	7	0.014	0.003	0.041	0.038	0.013	0.023	0.010	2.549	0.014	0.058
Processing/wet processing/flotation	23	0.006	0.002	0.019	0.017	0.005	0.008	0.005	2.183	0.006	0.009
Support/administration	6	0.010	0.003	0.023	0.020	0.008	0.016	0.008	2.110	0.010	0.031
Support/cleaners	8	0.004	0.002	0.012	0.010	0.003	0.006	0.003	1.812	0.004	0.007
Support/construction/buildings	3	0.003	0.002	0.003	0.001	0.001	0.004	0.003	1.264	0.003	0.005
Support/construction/plant	5	0.025	0.002	0.065	0.063	0.026	0.050	0.014	3.904	0.027	2.985
Support/fill/backfill	1	0.008	0.008	0.008	0.000	-	-	0.008	-	-	-
Support/fill/paste fill	26	0.013	0.002	0.048	0.046	0.012	0.017	0.008	2.597	0.013	0.021
Support/laundry	4	0.005	0.003	0.010	0.007	0.004	0.009	0.004	1.826	0.005	0.021
Support/logistics	32	0.008	0.001	0.044	0.043	0.010	0.011	0.004	3.001	0.008	0.013
Support/maintenance/boilermaker	45	0.021	0.002	0.208	0.206	0.037	0.030	0.008	3.868	0.020	0.036
Support/maintenance/electrical plant	79	0.013	0.001	0.110	0.109	0.019	0.017	0.006	3.268	0.012	0.017
Support/maintenance/fixed plant	166	0.017	0.001	0.365	0.364	0.036	0.021	0.007	3.408	0.014	0.018
Support/maintenance/mobile plant/breakdown	120	0.008	0.001	0.110	0.109	0.015	0.011	0.004	2.873	0.007	0.009
Support/maintenance/mobile plant/workshop	67	0.005	0.001	0.047	0.046	0.007	0.006	0.003	2.119	0.004	0.005
Support/maintenance/welder/field	2	0.164	0.017	0.310	0.293	0.207	1.088	0.073	7.791	0.163	-
Support/maintenance/welder/workshop	3	0.003	0.002	0.005	0.003	0.002	0.006	0.003	1.583	0.003	0.025
Support/not otherwise classified	31	0.024	0.002	0.380	0.378	0.073	0.046	0.005	3.807	0.012	0.026
Support/resource definition/surface rig/diamond	21	0.007	0.001	0.039	0.038	0.010	0.011	0.004	2.744	0.006	0.011
Support/resource definition/surface rig/reverse circula	14	0.088	0.002	0.390	0.388	0.123	0.146	0.021	7.522	0.115	2.171
Support/resource definition/underground rig	37	0.021	0.002	0.290	0.288	0.048	0.034	0.009	3.200	0.017	0.029
Support/technical/field	62	0.012	0.002	0.090	0.088	0.018	0.015	0.006	2.933	0.011	0.015
Support/technical/office	7	0.002	0.002	0.003	0.001	0.001	0.003	0.002	1.242	0.002	0.003
Surface/development/blasting/drill	10	0.170	0.010	0.620	0.610	0.197	0.284	0.082	3.952	0.181	1.250
Surface/development/excavator	2	0.002	0.002	0.002	0.000	0.000	0.002	0.002	1.000	0.002	-
Surface/development/rubber tyred loader	1	0.006	0.006	0.006	0.000	-	-	0.006	-	-	-
Surface/development/scraper	1	0.014	0.014	0.014	0.000	-	-	0.014	-	-	-
Surface/development/truck	4	0.002	0.002	0.002	0.000	0.000	0.002	0.002	1.000	0.002	0.002
Surface/not otherwise classified	27	0.008	0.001	0.038	0.037	0.008	0.011	0.005	2.579	0.008	0.013
Surface/production/excavator	1	0.003	0.003	0.003	0.000	-	-	0.003	-	-	-
Surface/production/rubber tyred loader	7	0.010	0.002	0.026	0.024	0.009	0.017	0.007	2.457	0.010	0.039
Surface/production/truck	14	0.004	0.001	0.012	0.011	0.003	0.006	0.003	2.172	0.004	0.008
Surface/services/road maintenance	8	0.004	0.002	0.017	0.015	0.005	0.008	0.003	2.141	0.004	0.009
Surface/services/water cart	2	0.015	0.003	0.027	0.024	0.017	0.091	0.009	4.729	0.015	-
Surface/technical/supervisor	4	0.002	0.002	0.002	0.000	0.000	0.002	0.002	1.000	0.002	0.002
Surface/technical/technical	6	0.059	0.002	0.200	0.198	0.077	0.122	0.020	6.829	0.072	76.612
Underground/development/charge up	132	0.032	0.001	0.670	0.669	0.064	0.041	0.015	3.315	0.031	0.040
Underground/development/drill/ long hole	62	0.020	0.001	0.120	0.119	0.023	0.025	0.011	3.134	0.021	0.031
Underground/development/drill/jumbo	175	0.020	0.001	0.216	0.215	0.030	0.023	0.010	3.077	0.019	0.024
Underground/development/drill/shaft sinking	10	0.026	0.002	0.091	0.089	0.026	0.041	0.017	2.914	0.027	0.093
Underground/ground control/shotcrete	86	0.018	0.001	0.167	0.166	0.024	0.022	0.009	3.446	0.018	0.026
Underground/ground control/strata stabilisation	20	0.016	0.002	0.089	0.087	0.021	0.023	0.007	3.553	0.016	0.039
Underground/not otherwise classified	152	0.019	0.001	0.390	0.389	0.036	0.024	0.010	3.169	0.019	0.023
Underground/production/loader	178	0.028	0.001	0.988	0.987	0.084	0.038	0.012	3.321	0.024	0.030
Underground/production/ring firer	24	0.019	0.002	0.083	0.081	0.019	0.026	0.012	3.065	0.021	0.040
Underground/production/truck	122	0.018	0.001	0.203	0.202	0.028	0.022	0.009	3.407	0.018	0.024
Underground/services/installation	187	0.033	0.001	0.398	0.397	0.051	0.040	0.016	3.333	0.034	0.042
Underground/services/refuel	43	0.014	0.001	0.058	0.057	0.015	0.017	0.008	3.109	0.014	0.023
Underground/services/water cart	37	0.012	0.002	0.076	0.074	0.015	0.016	0.006	2.926	0.011	0.018

Figure 49: Average RCS Exposure for Underground Metalliferous Mines by SEG

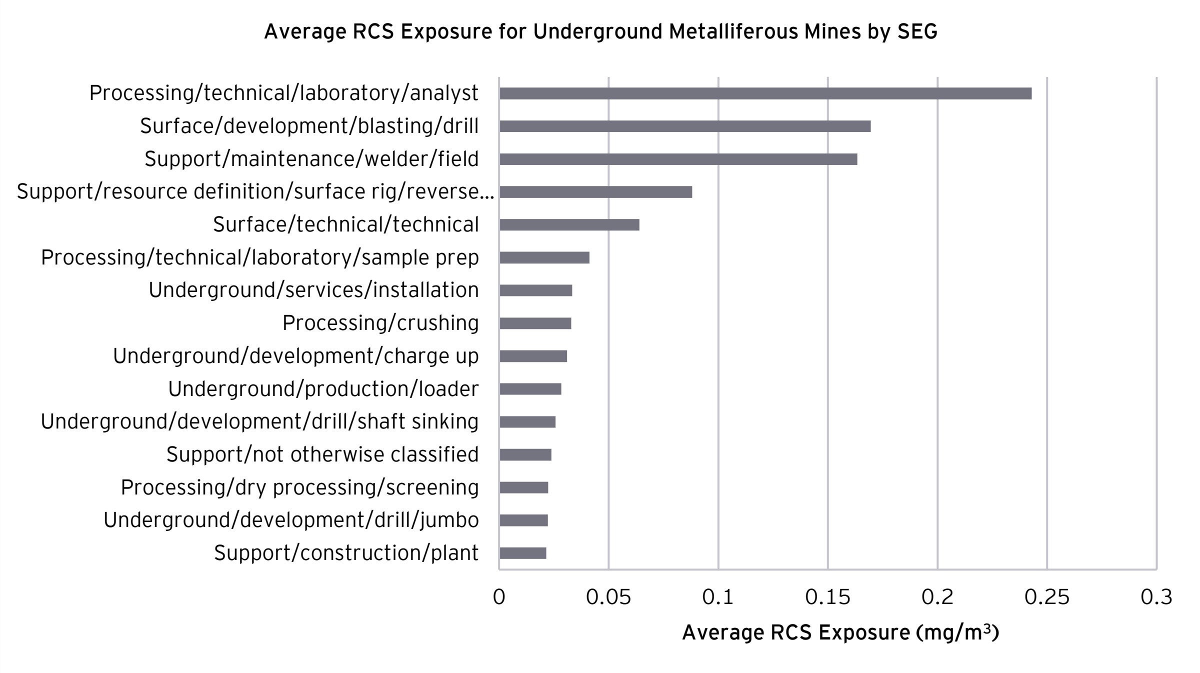


Table 91 and Figure 50 show the RCS exposures for the quarries. There are five SEGs with averages above the OEL. The export bagging had the highest average exposures at 0.11 mg/m^3 which only included one sample. Other bagging exposures should be investigated. In the quarry SEGs there are 7 UCLs and 9 Log UCLs over the OEL as well as 7 UCLs and 7 Log UCLs over half the OEL. This does not show that silica is well controlled in the sector.

Table 91: RCS Exposure for Quarry by SEG

Quarry SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	1	0.110	0.110	0.110	0.000	-	-	0.110	-	-	-
Export/truck-loading	93	0.006	0.002	0.048	0.046	0.007	0.007	0.005	1.880	0.006	0.007
N/A	155	0.036	0.005	0.700	0.695	0.090	0.048	0.013	3.313	0.027	0.034
Processing/crushing	275	0.027	0.002	0.681	0.679	0.052	0.032	0.013	3.131	0.025	0.030
Processing/dry processing/classification	1	0.020	0.020	0.020	0.000	-	-	0.020	-	-	-
Processing/dry processing/screening	25	0.027	0.003	0.347	0.344	0.068	0.050	0.011	3.071	0.020	0.038
Processing/not otherwise classified	40	0.017	0.002	0.140	0.138	0.031	0.025	0.008	3.069	0.014	0.023
Processing/technical/laboratory/analyst	32	0.014	0.003	0.120	0.117	0.025	0.022	0.008	2.386	0.012	0.017
Processing/technical/laboratory/sample prep	43	0.011	0.003	0.037	0.034	0.009	0.013	0.008	2.144	0.010	0.013
Processing/wet processing/screening	9	0.005	0.003	0.008	0.005	0.001	0.006	0.005	1.352	0.005	0.006
Support/administration	99	0.006	0.002	0.049	0.047	0.007	0.007	0.005	1.904	0.006	0.006
Support/cleaners	4	0.061	0.005	0.110	0.105	0.043	0.112	0.039	4.027	0.074	######
Support/construction/plant	5	0.008	0.003	0.012	0.009	0.004	0.012	0.006	2.007	0.008	0.029
Support/logistics	15	0.011	0.002	0.030	0.028	0.008	0.014	0.009	2.106	0.011	0.018
Support/maintenance/boilermaker	98	0.045	0.002	0.720	0.718	0.101	0.062	0.016	3.741	0.037	0.053
Support/maintenance/electrical plant	8	0.050	0.002	0.190	0.188	0.073	0.098	0.016	5.655	0.050	2.396
Support/maintenance/fixed plant	198	0.050	0.002	0.840	0.838	0.110	0.063	0.016	3.962	0.042	0.054
Support/maintenance/mobile plant/breakdown	29	0.025	0.002	0.270	0.268	0.051	0.041	0.010	3.595	0.021	0.043
Support/maintenance/mobile plant/workshop	33	0.014	0.002	0.130	0.128	0.024	0.021	0.007	2.913	0.012	0.019
Support/maintenance/welder/field	7	0.015	0.002	0.050	0.048	0.016	0.027	0.010	2.861	0.015	0.088
Support/maintenance/welder/workshop	26	0.050	0.003	0.270	0.267	0.077	0.076	0.019	4.065	0.047	0.116
Support/not otherwise classified	34	0.010	0.002	0.050	0.048	0.013	0.014	0.006	2.519	0.009	0.014
Support/technical/field	40	0.013	0.002	0.070	0.068	0.017	0.018	0.008	2.555	0.012	0.017
Support/technical/office	13	0.006	0.002	0.010	0.008	0.004	0.008	0.005	2.050	0.006	0.010
Surface/development/blasting/charge up	5	0.012	0.010	0.020	0.010	0.004	0.016	0.011	1.363	0.012	0.017
Surface/development/blasting/drill	56	0.014	0.002	0.320	0.318	0.042	0.024	0.007	2.496	0.011	0.014
Surface/development/dozer	12	0.015	0.002	0.040	0.038	0.012	0.022	0.011	2.551	0.016	0.037
Surface/development/excavator	43	0.010	0.002	0.110	0.108	0.017	0.014	0.006	2.147	0.009	0.011
Surface/development/rubber tyred loader	43	0.010	0.002	0.070	0.068	0.015	0.014	0.006	2.438	0.009	0.012
Surface/development/scraper	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Surface/development/truck	20	0.006	0.002	0.030	0.028	0.006	0.008	0.005	1.911	0.006	0.008
Surface/not otherwise classified	140	0.026	0.002	0.410	0.408	0.048	0.032	0.011	3.258	0.022	0.028
Surface/production/excavator	213	0.013	0.002	0.310	0.308	0.028	0.016	0.007	2.580	0.011	0.013
Surface/production/rubber tyred loader	342	0.011	0.002	0.420	0.418	0.025	0.013	0.006	2.358	0.009	0.010
Surface/production/train	23	0.051	0.003	0.630	0.627	0.129	0.097	0.018	3.477	0.037	0.082
Surface/production/truck	267	0.012	0.002	0.410	0.408	0.029	0.015	0.007	2.401	0.010	0.011
Surface/services/refuel	3	0.006	0.002	0.013	0.011	0.006	0.016	0.004	2.677	0.006	51.476
Surface/services/road maintenance	9	0.064	0.002	0.470	0.468	0.153	0.158	0.016	4.351	0.038	0.441
Surface/services/water cart	68	0.013	0.002	0.120	0.118	0.022	0.017	0.007	2.507	0.011	0.014
Surface/technical/supervisor	123	0.012	0.002	0.150	0.148	0.018	0.014	0.007	2.325	0.010	0.012
Surface/technical/technical	10	0.008	0.003	0.020	0.017	0.005	0.011	0.007	1.738	0.008	0.012

Figure 50: Average RCS Exposure for Quarry by SEG

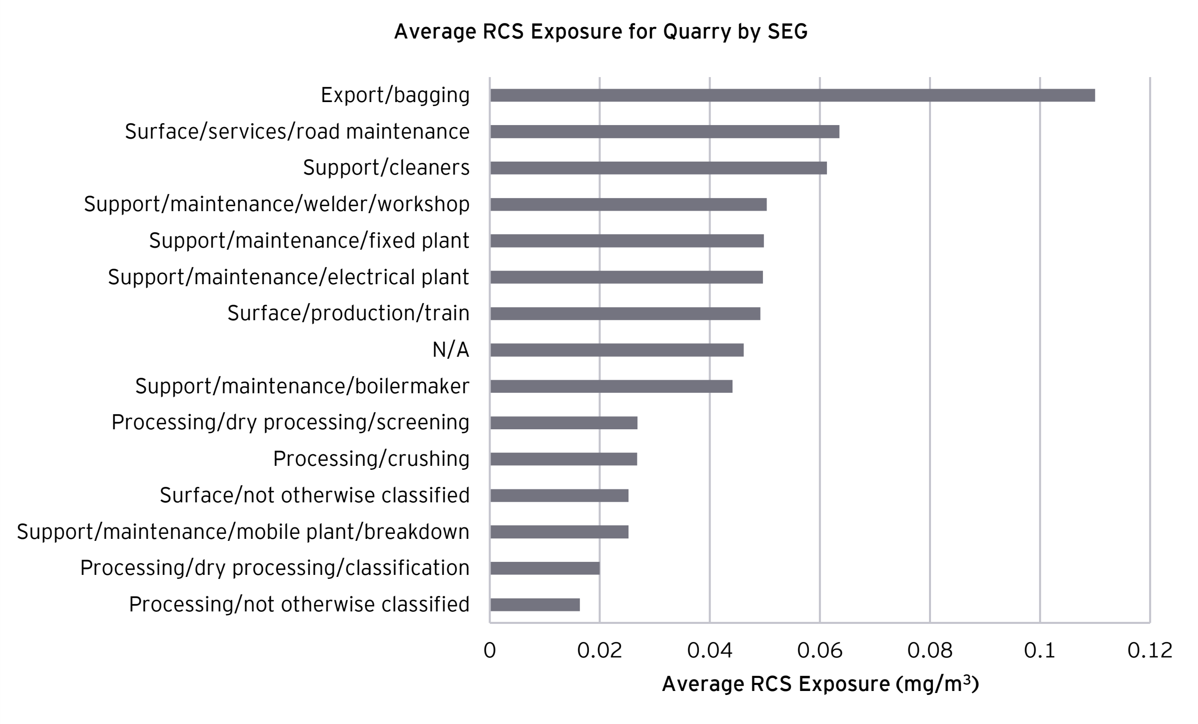


Table 92 and Figure 51 show the RCS exposures for Quarry – group, which have a small number of samples. The technical/supervisor has the highest average exposure and the only exposure over half of the OEL, it should be noted that there are only 2 samples taken for this SEG. Many of the SEGs do not have enough samples to calculate the Log UCL.

Table 92: RCS Exposure for Quarry – Group by SEG

Quarry Group SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/truck-loading	3	0.012	0.005	0.020	0.015	0.008	0.025	0.010	2.000	0.012	1.035
Processing/crushing	8	0.005	0.003	0.011	0.008	0.003	0.007	0.005	1.507	0.005	0.008
Support/technical/field	2	0.004	0.003	0.005	0.002	0.001	0.010	0.004	1.435	0.004	-
Surface/development/dozer	5	0.010	0.004	0.018	0.014	0.005	0.015	0.009	1.713	0.010	0.024
Surface/development/rubber tyred loader	1	0.003	0.003	0.003	0.000	-	-	0.003	-	-	-
Surface/not otherwise classified	7	0.014	0.004	0.049	0.045	0.016	0.026	0.010	2.396	0.014	0.048
Surface/production/excavator	2	0.005	0.005	0.005	0.000	0.000	0.005	0.005	1.000	0.005	-
Surface/production/rubber tyred loader	8	0.018	0.004	0.058	0.054	0.019	0.031	0.012	2.719	0.018	0.071
Surface/services/water cart	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Surface/technical/supervisor	2	0.033	0.005	0.061	0.056	0.040	0.210	0.017	5.864	0.033	-

Figure 51: Average RCS Exposure for Quarry- Group by SEG

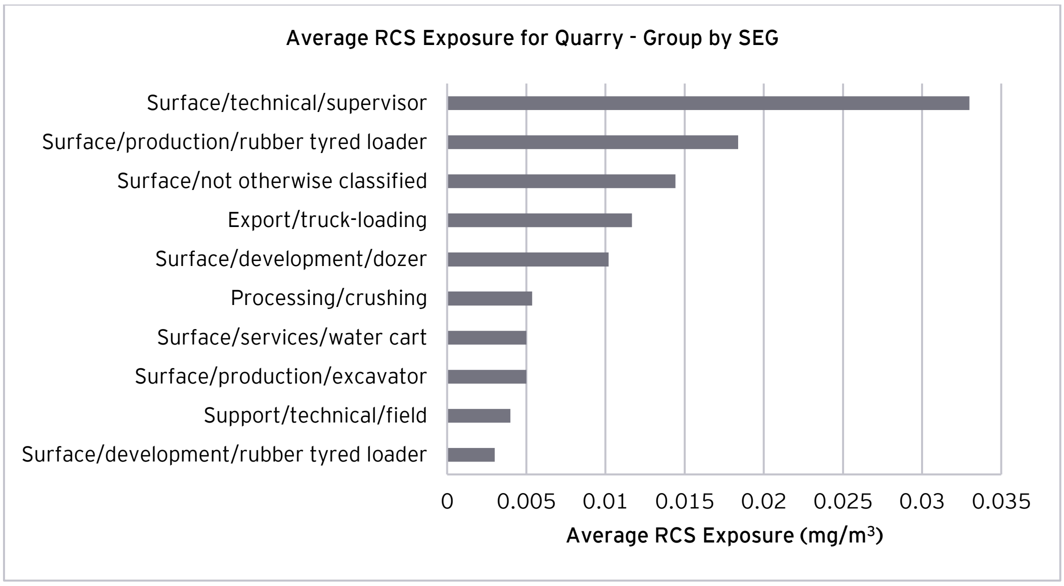


Table 93 and Figure 52 show the RCS exposures for the mineral processing SEGs. The SEG with the highest average was surface/development/blast/drilling, which also had a geometric mean, UCL and Log UCL over the OEL. There were four SEGs with averages above half the OEL including processing/dewatering, processing/technical/science and engineering, support/not otherwise classified and surface/development/dozer. Six SEGs have a UCL and 12 have a Log UCL over the OEL. There are also five SEGs with a UCL above half the OEL and four SEG with a Log UCL above half the OEL.

Similar to the comment made in the Mineral Processing RD section, these SEGs should be reviewed for applicability to the mine type. While some activities such as dozer operation could take place in the mine as well as at the mineral processing facility there are others such as underground long hole and jumbo drilling that are clearly not a mineral processing task.

Table 93: RCS Exposure for Processing by SEG

Processing SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/truck-loading	2	0.007	0.005	0.008	0.003	0.002	0.016	0.006	1.394	0.006	-
Processing/crushing	57	0.014	0.001	0.131	0.130	0.022	0.019	0.008	2.845	0.013	0.018
Processing/dewatering	9	0.041	0.002	0.330	0.328	0.108	0.109	0.007	4.981	0.020	0.359
Processing/dry processing/screening	7	0.009	0.001	0.026	0.025	0.008	0.015	0.006	2.738	0.010	0.049
Processing/not otherwise classified	50	0.015	0.001	0.249	0.248	0.042	0.025	0.004	3.619	0.010	0.016
Processing/smelting	86	0.014	0.001	0.904	0.903	0.097	0.032	0.003	2.574	0.005	0.006
Processing/technical/laboratory/sample prep	7	0.018	0.002	0.060	0.058	0.022	0.033	0.009	3.744	0.017	0.250
Processing/technical/science and engineering	11	0.044	0.002	0.447	0.445	0.134	0.117	0.005	4.841	0.015	0.146
Processing/wet processing/cutting	7	0.013	0.002	0.032	0.030	0.010	0.021	0.010	2.440	0.014	0.050
Processing/wet processing/flotation	11	0.007	0.002	0.032	0.030	0.010	0.012	0.004	2.777	0.006	0.016
Processing/wet processing/heap leach	5	0.005	0.002	0.012	0.010	0.004	0.009	0.004	2.290	0.005	0.029
Processing/wet processing/screening	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Processing/wet processing/solvent extraction	1	0.003	0.003	0.003	0.000	-	-	0.003	-	-	-
Support/cleaners	7	0.006	0.001	0.028	0.027	0.010	0.013	0.003	2.928	0.005	0.031
Support/construction/buildings	1	0.019	0.019	0.019	0.000	-	-	0.019	-	-	-
Support/fill/paste fill	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Support/laundry	11	0.005	0.001	0.018	0.017	0.005	0.008	0.003	2.326	0.005	0.010
Support/logistics	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Support/maintenance/boilermaker	26	0.006	0.001	0.017	0.016	0.004	0.007	0.004	2.034	0.006	0.008
Support/maintenance/electrical plant	42	0.004	0.001	0.015	0.014	0.003	0.005	0.003	1.971	0.004	0.005
Support/maintenance/fixed plant	33	0.007	0.002	0.038	0.036	0.008	0.009	0.005	2.361	0.006	0.009
Support/maintenance/mobile plant/breakdown	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Support/maintenance/mobile plant/workshop	9	0.007	0.003	0.020	0.017	0.006	0.011	0.006	2.039	0.007	0.015
Support/maintenance/welder/field	1	0.007	0.007	0.007	0.000	-	-	0.007	-	-	-
Support/not otherwise classified	12	0.035	0.001	0.288	0.287	0.081	0.077	0.006	6.237	0.024	0.392
Support/technical/field	7	0.004	0.002	0.012	0.010	0.004	0.007	0.003	1.899	0.004	0.008
Support/technical/office	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Surface/development/blasting/drill	13	0.622	0.011	2.500	2.489	0.838	1.036	0.238	4.822	0.689	4.787
Surface/development/dozer	2	0.033	0.010	0.055	0.045	0.032	0.175	0.023	3.338	0.032	-
Surface/development/excavator	2	0.006	0.002	0.009	0.007	0.005	0.028	0.004	2.897	0.005	-
Surface/development/rubber tyred loader	3	0.004	0.002	0.007	0.005	0.003	0.008	0.003	1.895	0.004	0.180
Surface/development/truck	2	0.004	0.002	0.005	0.003	0.002	0.013	0.003	1.912	0.003	-
Surface/production/excavator	7	0.011	0.002	0.047	0.045	0.016	0.023	0.006	3.057	0.010	0.068
Surface/production/rubber tyred loader	7	0.006	0.002	0.011	0.009	0.003	0.009	0.006	1.754	0.006	0.012
Surface/production/truck	3	0.005	0.003	0.008	0.005	0.003	0.010	0.005	1.633	0.005	0.052
Surface/technical/supervisor	6	0.011	0.002	0.022	0.020	0.008	0.018	0.008	2.664	0.012	0.076
Surface/technical/technical	5	0.018	0.010	0.028	0.018	0.007	0.025	0.017	1.496	0.018	0.031
Underground/development/charge up	3	0.012	0.005	0.020	0.015	0.008	0.025	0.010	2.004	0.012	1.100
Underground/development/drill/ long hole	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Underground/development/drill/jumbo	4	0.010	0.003	0.020	0.017	0.008	0.018	0.007	2.285	0.009	0.148
Underground/not otherwise classified	2	0.007	0.003	0.010	0.007	0.005	0.029	0.005	2.343	0.006	-
Underground/production/loader	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Underground/production/truck	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Underground/services/installation	2	0.013	0.005	0.020	0.015	0.011	0.060	0.010	2.665	0.012	-

Figure 52: Average RCS Exposure for Processing by SEG

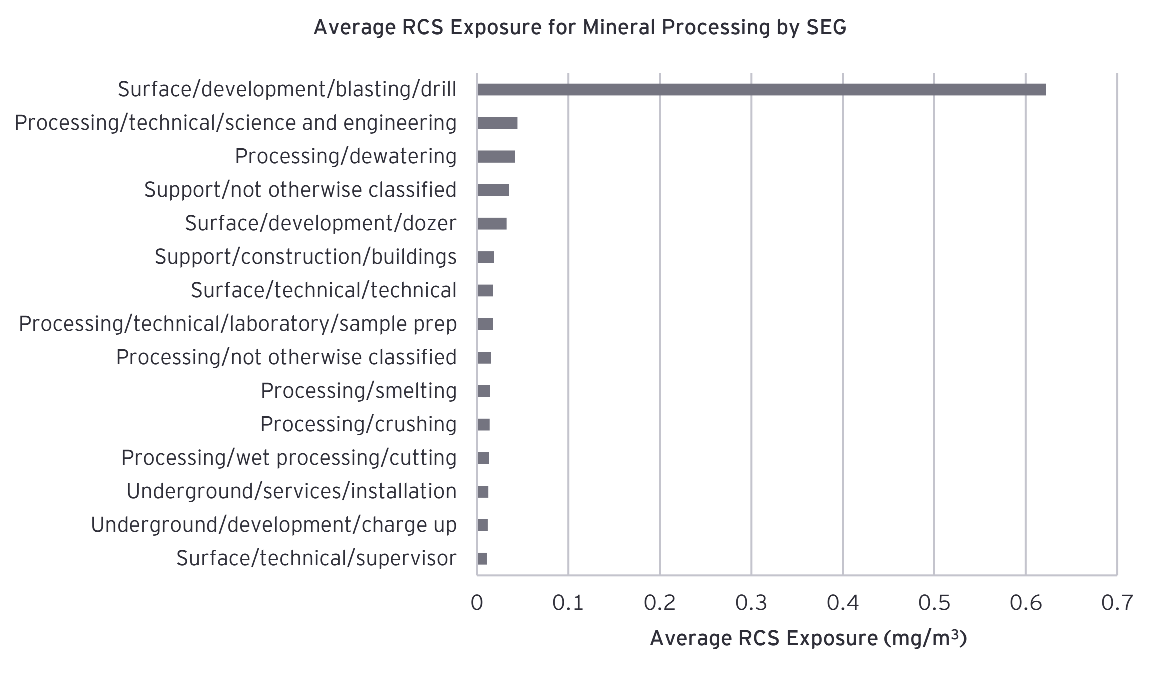


Table 94 and Figure 53 show the RCS exposures for the exploration SEGs. There were very few samples overall with no SEG having more than nine samples. The support/resource definition/surface rig/reverse circulation and underground/development/drill/long hole SEGs had the higher averages. Underground/development/drill/long hole and underground/services/installation both had averages and geometric means above the OEL.

There are only nine SEGs with enough samples to calculate a Log UCL. Of those samples six Log UCLs are above the OEL, one more is above half the OEL and only two are below half of the Log UCL.

Table 94: RCS Exposure for Exploration by SEG

Exploration SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/technical/laboratory/sample prep	1	0.021	0.021	0.021	0.000	-	-	0.021	-	-	-
Processing/wet processing/flotation	3	0.003	0.002	0.003	0.001	0.001	0.004	0.003	1.264	0.003	0.005
Support/logistics	2	0.005	0.003	0.006	0.003	0.002	0.014	0.004	1.633	0.004	-
Support/maintenance/electrical plant	2	0.005	0.005	0.005	0.000	0.000	0.005	0.005	1.000	0.005	-
Support/maintenance/fixed plant	2	0.015	0.003	0.027	0.024	0.017	0.091	0.009	4.729	0.015	-
Support/maintenance/mobile plant/workshop	1	0.040	0.040	0.040	0.000	-	-	0.040	-	-	-
Support/not otherwise classified	3	0.002	0.002	0.003	0.001	0.001	0.003	0.002	1.264	0.002	0.004
Support/resource definition/surface rig/diamond	2	0.003	0.003	0.003	0.000	0.000	0.003	0.003	1.000	0.003	-
Support/resource definition/surface rig/reverse circula	9	0.070	0.002	0.280	0.278	0.111	0.139	0.009	9.930	0.065	24.631
Support/technical/field	4	0.025	0.003	0.061	0.058	0.028	0.057	0.011	4.798	0.025	######
Surface/production/rubber tyred loader	1	0.007	0.007	0.007	0.000	-	-	0.007	-	-	-
Surface/production/truck	6	0.007	0.002	0.019	0.017	0.007	0.012	0.005	2.406	0.006	0.030
Surface/services/road maintenance	1	0.003	0.003	0.003	0.000	-	-	0.003	-	-	-
Surface/technical/technical	2	0.003	0.003	0.003	0.000	0.000	0.003	0.003	1.000	0.003	-
Underground/development/charge up	4	0.048	0.039	0.055	0.016	0.007	0.056	0.047	1.167	0.048	0.059
Underground/development/drill/ long hole	3	0.069	0.023	0.110	0.087	0.044	0.143	0.057	2.261	0.071	35.704
Underground/not otherwise classified	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Underground/production/loader	3	0.012	0.007	0.022	0.015	0.009	0.027	0.010	1.937	0.012	0.699
Underground/production/truck	3	0.026	0.011	0.035	0.024	0.013	0.048	0.023	1.904	0.026	1.270
Underground/services/installation	1	0.062	0.062	0.062	0.000	-	-	0.062	-	-	-

Figure 53: Average RCS Exposure for Metalliferous Mine Exploration by SEG

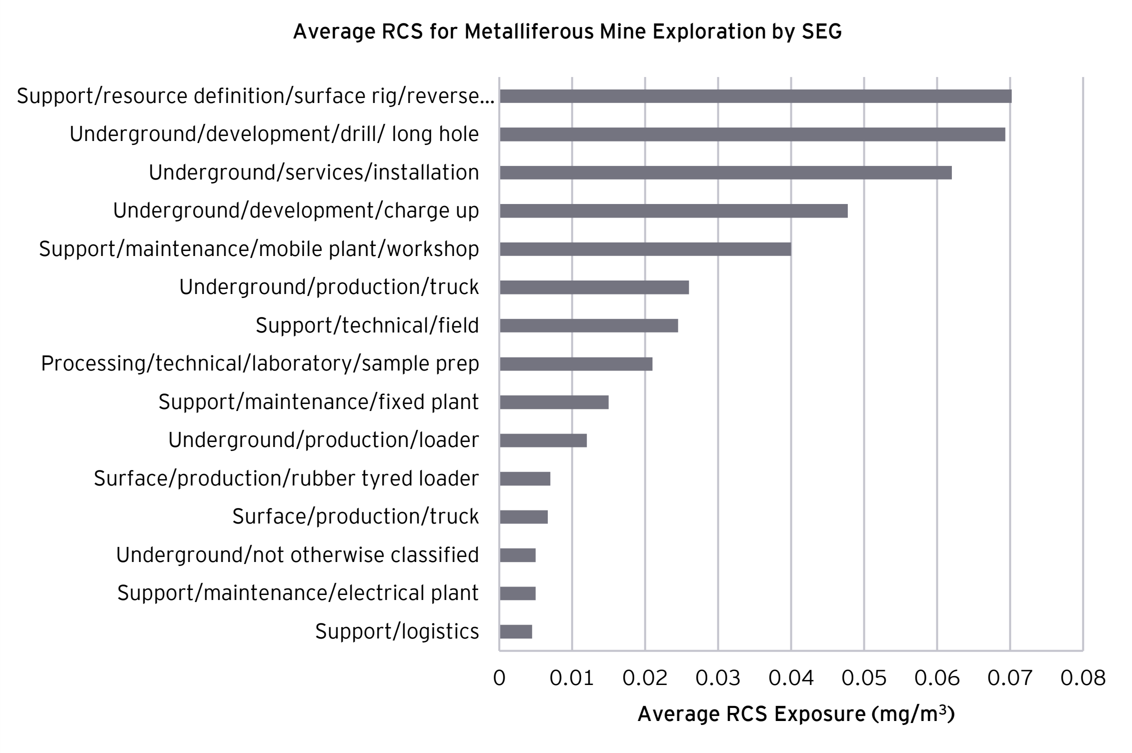


Table 95 and Figure 54 show the RCS Exposures for Dredging by SEG. There are very few samples in most of the SEGs. The highest average exposures are in the surface/services/refuel and the support/maintenance/mobile plant/breakdown SEGs, which have both the average and the geometric mean above half the OEL. Of the 14 SEGs with enough samples to calculate the UCL, three are above the OEL, six more are above half the OEL and only five are below half the OEL. Of the nine SEGs with enough samples to calculate the Log UCL, seven are above the OEL and only two are below half the OEL.

That does not indicate that these exposures are well controlled and more sampling is needed to better quantify these SEGs.

Table 95: RCS Exposure for Dredging by SEG

RCS for Dredging SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/not otherwise classified	3	0.023	0.010	0.040	0.030	0.015	0.049	0.020	2.000	0.023	2.070
Processing/wet processing/cutting	2	0.013	0.006	0.019	0.013	0.009	0.054	0.011	2.259	0.012	-
Processing/wet processing/screening	1	0.005	0.005	0.005	0.000	-	-	0.005	-	-	-
Support/administration	2	0.004	0.003	0.005	0.002	0.001	0.010	0.004	1.435	0.004	-
Support/fill/backfill	3	0.010	0.005	0.020	0.015	0.009	0.025	0.008	2.226	0.010	3.872
Support/logistics	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Support/maintenance/electrical plant	4	0.018	0.005	0.040	0.035	0.017	0.037	0.012	2.828	0.017	1.287
Support/maintenance/fixed plant	8	0.021	0.003	0.120	0.117	0.040	0.048	0.008	3.445	0.015	0.113
Support/maintenance/mobile plant/breakdown	2	0.035	0.011	0.059	0.048	0.034	0.187	0.025	3.279	0.035	-
Support/maintenance/welder/workshop	1	0.002	0.002	0.002	0.000	-	-	0.002	-	-	-
Support/not otherwise classified	13	0.008	0.003	0.020	0.017	0.006	0.011	0.007	1.802	0.008	0.012
Support/technical/office	2	0.004	0.003	0.005	0.002	0.001	0.010	0.004	1.435	0.004	-
Surface/development/dozer	6	0.023	0.003	0.040	0.037	0.017	0.037	0.015	3.217	0.026	0.349
Surface/development/excavator	3	0.016	0.009	0.030	0.021	0.012	0.036	0.014	1.948	0.016	1.021
Surface/not otherwise classified	8	0.025	0.006	0.060	0.054	0.017	0.036	0.020	2.052	0.025	0.054
Surface/production/rubber tyred loader	2	0.029	0.008	0.050	0.042	0.030	0.162	0.020	3.654	0.029	-
Surface/production/train	3	0.007	0.005	0.008	0.003	0.002	0.010	0.007	1.312	0.007	0.015
Surface/services/refuel	1	0.039	0.039	0.039	0.000	-	-	0.039	-	-	-

Figure 54: Average RCS Exposure for Dredging by SEG

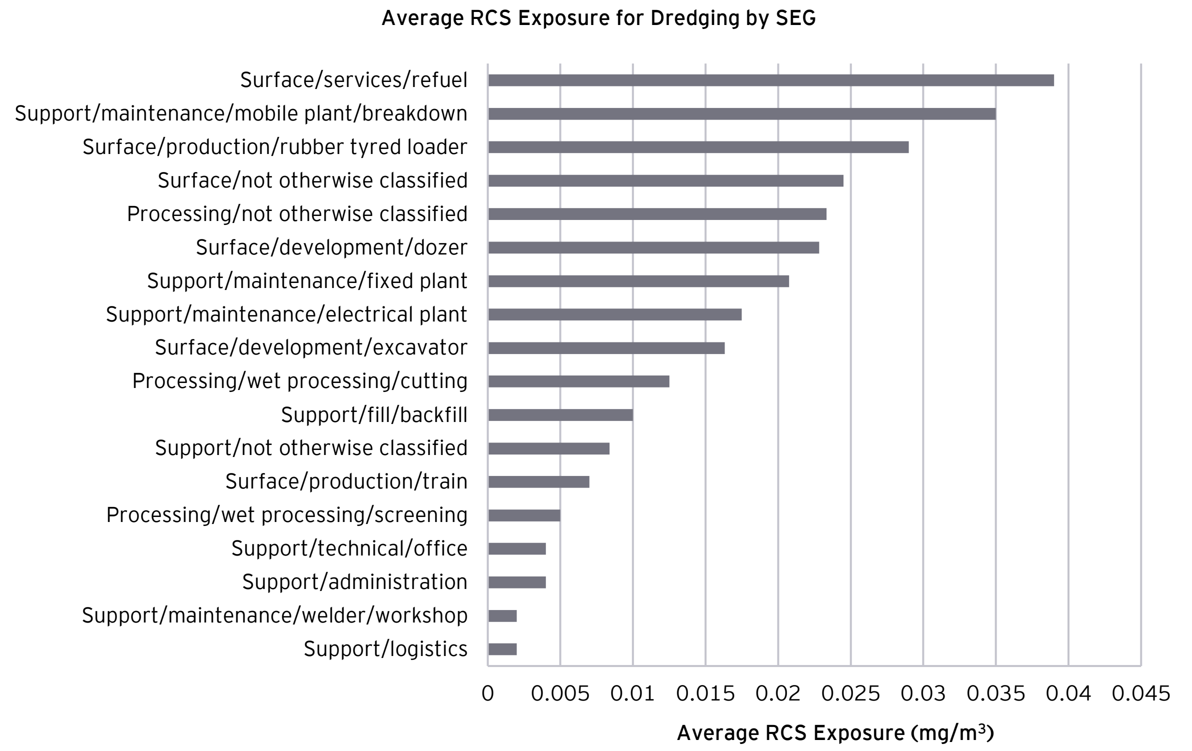
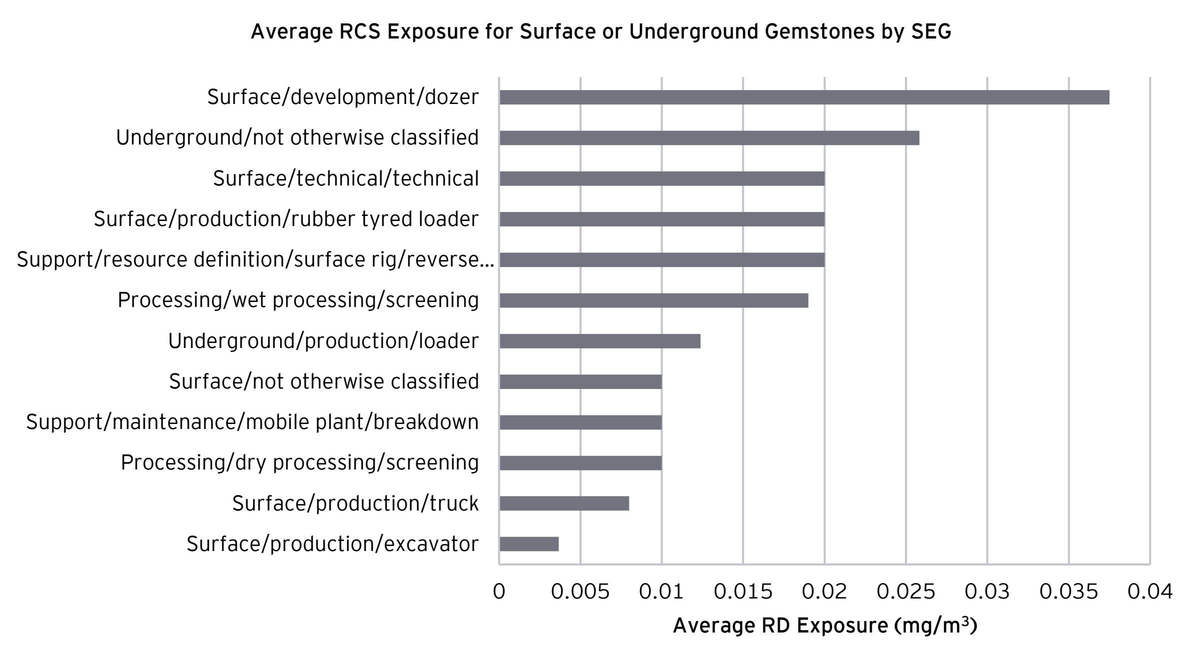


Table 96 and Figure 55 show the RCS exposures for surface or underground gemstones by SEG. There are very few samples in most of the SEGs. The highest average exposures are in the surface/development/dozer and the underground/not otherwise classified SEGs. The surface/development/dozer also has a geometric mean above half the OEL and a UCL above the OEL. The underground/not otherwise classified SEG has both the average and UCL above half the OEL, the geo mean is below half the OEL, but the Log UCL is above the OEL.

Table 96: RCS Exposure for Surface or Underground Gemstone by SEG

Surface or Underground Gemstone SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/dry processing/screening	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Processing/wet processing/screening	1	0.019	0.019	0.019	0.000	-	-	0.019	-	-	-
Support/maintenance/mobile plant/breakdown	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Support/resource definition/surface rig/reverse circula	1	0.020	0.020	0.020	0.000	-	-	0.020	-	-	-
Surface/development/dozer	2	0.038	0.035	0.040	0.005	0.004	0.053	0.037	1.099	0.038	-
Surface/not otherwise classified	2	0.010	0.010	0.010	0.000	0.000	0.010	0.010	1.000	0.010	-
Surface/production/excavator	3	0.004	0.001	0.005	0.004	0.002	0.008	0.003	2.533	0.004	12.488
Surface/production/rubber tyred loader	2	0.020	0.020	0.020	0.000	0.000	0.020	0.020	1.000	0.020	-
Surface/production/truck	1	0.008	0.008	0.008	0.000	-	-	0.008	-	-	-
Surface/technical/technical	1	0.020	0.020	0.020	0.000	-	-	0.020	-	-	-
Underground/not otherwise classified	12	0.026	0.005	0.070	0.065	0.022	0.037	0.018	2.395	0.026	0.054
Underground/production/loader	12	0.012	0.005	0.030	0.025	0.009	0.017	0.010	1.929	0.012	0.020

Figure 55: Average RCS Exposure for Surface or Underground Gemstones by SEG

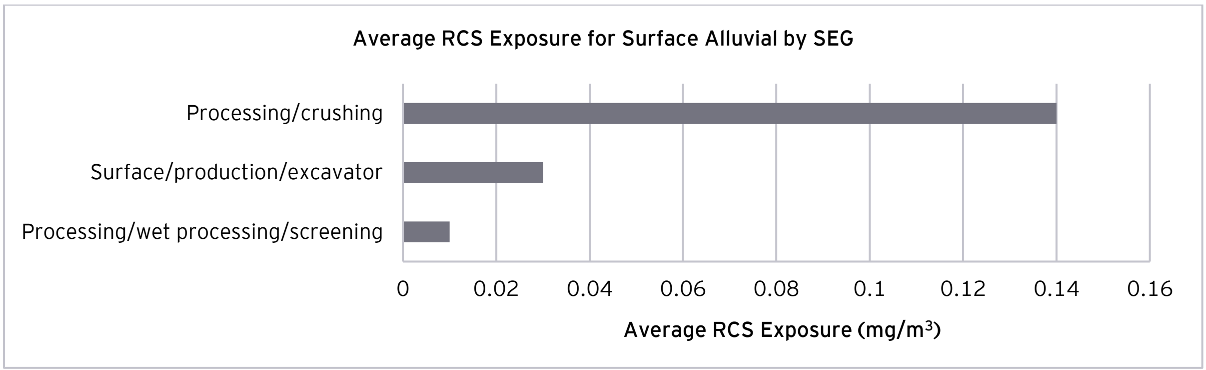


Only 3 samples were taken in the surface alluvial gold sector which are shown in Table 97 and Figure 56 One each of these are above the OEL, above half the OEL and below half the OEL. If these activities are taking place regularly in Queensland, more samples should be taken to better quantify the exposure of the sector.

Table 97: RCS Exposure for Surface Alluvial by SEG

Surface Alluvial SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/crushing	1	0.140	0.140	0.140	0.000	-	-	0.140	-	-	-
Processing/wet processing/screening	1	0.010	0.010	0.010	0.000	-	-	0.010	-	-	-
Surface/production/excavator	1	0.030	0.030	0.030	0.000	-	-	0.030	-	-	-

Figure 56: Average RCS Exposure for Surface Alluvial by SEG



Appendix H Mineral mines and quarries—Respirable dust

Very few samples are in the data set for quarry-group, surface or underground gemstone, surface alluvial gold, exploration and dredging operations. This makes it difficult to accurately estimate the exposures for these groups.

Respirable crystalline silica exposure is a more significant issue than total respirable dust exposure based on current exposure samples. However, the amount of other silicates and other mineralogical components is not taken into account in total dust levels.

Some mine types have large numbers of samples in "N/A" or "not otherwise classified" SEG categories. The SEGs should be reviewed for adequacy and the data coming in should be reviewed for appropriate categorisation. Many of the N/A or NOC classifications clearly belong in another SEG group based on primary activity listed.

The mineral processing mine type should be reviewed for the applicability of all SEGs attributed to this mine type. Some clearly look to be mining activities and not mineral processing.

Several SEGs should be the subject of further investigation:

- ► Shotcreting- ensure adequate RPE to protect workers performing the task and anyone in the area.
- ► Cleaners- there were only 4 samples from quarry cleaners, but one was 19.54 mg/m^3 and the comments indicated that this is representative of the workers exposure.

A total of 7,337 samples were analysed for the Mineral Mines and Quarries data for the 2017 to 2020 period. These covered the areas of mineral processing, dredging operations, exploration, surface, surface alluvial gold, surface or underground gemstone, underground, quarry and quarry - group. Quarry, surface and underground mine types were the only groups with over 100 samples as can be seen in Table 98 below. Many of the other mine types have very few samples taken, which may not be representative of the sector as a whole.

Table 98: Mineral Mines and Quarries RD Exposure by Mine Type

MMQ Exposure by Mine Type	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Metalliferous - Minerals Processing	471	0.504	0.001	28.322	28.321	2.087	0.662	0.144	3.553	0.321	0.370
Metalliferous - Quarry	2667	0.279	0.005	19.54	19.535	0.733	0.302	0.121	3.207	0.239	0.252
Metalliferous Mine - Dredging Operation	65	0.083	0.005	1.49	1.485	0.181	0.120	0.052	2.307	0.073	0.091
Metalliferous Mine - Exploration	54	0.354	0.05	2.4	2.35	0.489	0.465	0.181	3.079	0.334	0.494
Metalliferous Mine - Surface	1427	0.235	0.001	4.3	4.299	0.428	0.254	0.120	2.869	0.208	0.222
Metalliferous Mine - Surface Alluvial Gold	3	0.493	0.13	1.03	0.9	0.474	1.293	0.350	2.823	0.487	-
Metalliferous Mine - Surface or Underground Gemstone	39	0.386	0.01	2.5	2.49	0.454	0.508	0.229	3.031	0.413	0.660
Metalliferous Mine - Underground	2572	0.337	0.001	14.904	14.903	0.665	0.359	0.171	3.152	0.330	0.348
Metalliferous Quarry - Group	39	0.116	0.01	0.5	0.49	0.104	0.144	0.082	2.393	0.119	0.165
Total	7337	0.304	0.001	28.322	28.321	0.820	0.320	0.138	3.180	0.269	0.277

Table 99 shows the respirable dust exposure for surface metalliferous mines by SEG. Many of these SEGs only had a number of samples in the single digits over the 2017 to 2020 period.

The one shotcrete sample shows a value of 4.1 mg/m^3, which is shown as the highest average exposure in Figure 57. Adequate RPE should be ensured for those performing shotcreting activities and anyone in the vicinity. Shotcreting produces many respirable particles that stay entrained in the mine air. Researchers observed sustained exposures of 8 mg/m^3 in a coal mine measured with real-time monitoring approximately 250m from where shotcrete was being applied.

Table 99: RD Exposure for Surface Metalliferous Mines by SEG

Surface SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	50	0.522	0.05	2.727	2.677	0.664	0.680	0.285	2.988	0.509	0.754
Export/ship loading	4	0.075	0.05	0.1	0.05	0.029	0.109	0.071	1.492	0.075	0.161
Export/train-loading	2	0.110	0.11	0.11	0	0.000	0.110	0.110	1.000	0.110	-
Export/truck-loading	29	0.171	0.03	0.762	0.732	0.159	0.221	0.126	2.138	0.167	0.230
Processing/crushing	64	0.414	0.05	3.49	3.44	0.576	0.534	0.235	2.764	0.389	0.527
Processing/dewatering	5	0.090	0.05	0.1	0.05	0.022	0.111	0.087	1.363	0.090	0.132
Processing/dry processing/classification	19	0.433	0.06	2.445	2.385	0.607	0.674	0.238	2.848	0.395	0.790
Processing/dry processing/cutting	9	0.267	0.05	0.7	0.65	0.232	0.410	0.189	2.475	0.269	0.749
Processing/dry processing/screening	19	0.409	0.05	3.2	3.15	0.773	0.716	0.170	3.286	0.326	0.769
Processing/not otherwise classified	65	0.164	0.01	0.7	0.69	0.171	0.200	0.107	2.525	0.163	0.212
Processing/smelting	14	0.154	0.05	0.4	0.35	0.112	0.206	0.128	1.792	0.150	0.215
Processing/technical/laboratory/analyst	24	0.318	0.05	2.4	2.35	0.517	0.499	0.153	3.096	0.277	0.539
Processing/technical/laboratory/sample prep	63	0.275	0.03	1.4	1.37	0.286	0.335	0.164	2.838	0.279	0.384
Processing/technical/science and engineering	22	0.382	0.01	2.5	2.49	0.615	0.608	0.157	3.754	0.351	0.883
Processing/wet processing/carbon-in-pulp	3	0.167	0.1	0.2	0.1	0.058	0.264	0.159	1.492	0.167	-
Processing/wet processing/cutting	24	0.126	0.03	0.4	0.37	0.088	0.157	0.104	1.868	0.125	0.165
Processing/wet processing/electro-winning	2	0.075	0.05	0.1	0.05	0.035	0.233	0.071	1.633	0.075	-
Processing/wet processing/flotation	14	0.284	0.05	1.9	1.85	0.479	0.510	0.152	2.712	0.239	0.537
Processing/wet processing/heap leach	4	0.138	0.05	0.3	0.25	0.111	0.268	0.111	2.098	0.135	1.261
Processing/wet processing/screening	32	0.085	0.05	0.4	0.35	0.076	0.107	0.069	1.742	0.080	0.098
Processing/wet processing/solvent extraction	11	0.227	0.1	0.5	0.4	0.149	0.309	0.187	1.929	0.226	0.379
Support/administration	16	0.075	0.005	0.4	0.395	0.090	0.115	0.049	2.834	0.080	0.174
Support/cleaners	12	0.141	0.05	0.7	0.65	0.181	0.235	0.098	2.118	0.126	0.227
Support/construction/plant	5	0.196	0.05	0.5	0.45	0.209	0.395	0.116	3.180	0.190	5.770
Support/laundry	2	0.170	0.154	0.185	0.031	0.022	0.267	0.169	1.138	0.170	-
Support/logistics	32	0.123	0.02	0.5	0.48	0.108	0.155	0.092	2.139	0.121	0.164
Support/maintenance/boilermaker	19	0.581	0.05	2.67	2.62	0.822	0.908	0.261	3.555	0.544	1.416
Support/maintenance/electrical plant	36	0.096	0.007	0.4	0.393	0.073	0.117	0.077	1.999	0.097	0.125
Support/maintenance/fixed plant	130	0.211	0.001	1.62	1.619	0.225	0.243	0.129	2.944	0.229	0.286
Support/maintenance/mobile plant/breakdown	52	0.194	0.047	2.6	2.553	0.360	0.278	0.126	2.116	0.165	0.206
Support/maintenance/mobile plant/workshop	39	0.165	0.005	1	0.995	0.201	0.219	0.091	3.182	0.173	0.286
Support/maintenance/welder/field	8	0.326	0.05	2.1	2.05	0.717	0.807	0.106	3.466	0.200	1.538
Support/maintenance/welder/workshop	14	0.756	0.05	3.1	3.05	0.944	1.203	0.355	3.813	0.782	3.007
Support/not otherwise classified	32	0.159	0.013	0.89	0.877	0.219	0.225	0.090	2.699	0.144	0.225
Support/resource definition/surface rig/diamond	4	0.063	0.05	0.1	0.05	0.025	0.092	0.059	1.414	0.062	0.114
Support/resource definition/surface rig/reverse circulation	10	1.851	0.4	4.3	3.9	1.341	2.628	1.399	2.293	1.892	4.214
Support/technical/field	36	0.369	0.02	3.8	3.78	0.740	0.577	0.144	3.341	0.287	0.505
Support/technical/office	22	0.100	0.05	0.7	0.65	0.136	0.150	0.076	1.815	0.090	0.118
Surface/development/blasting/charge up	28	0.156	0.02	0.666	0.646	0.148	0.204	0.108	2.423	0.157	0.236
Surface/development/blasting/drill	39	0.167	0.005	0.8	0.795	0.181	0.216	0.110	2.580	0.170	0.245
Surface/development/dozer	24	0.148	0.05	1.2	1.15	0.236	0.230	0.099	2.035	0.126	0.175
Surface/development/excavator	23	0.087	0.03	0.2	0.17	0.053	0.106	0.075	1.711	0.086	0.109
Surface/development/rubber tyred loader	14	0.241	0.03	1.4	1.37	0.361	0.412	0.123	3.088	0.217	0.587
Surface/development/scraper	4	0.063	0.02	0.13	0.11	0.047	0.118	0.050	2.147	0.062	0.667
Surface/development/truck	35	0.112	0.02	0.58	0.56	0.095	0.139	0.093	1.794	0.109	0.134
Surface/not otherwise classified	25	0.335	0.01	1.7	1.69	0.500	0.506	0.143	3.626	0.311	0.694
Surface/production/excavator	50	0.140	0.01	1	0.99	0.170	0.180	0.089	2.563	0.137	0.187
Surface/production/rubber tyred loader	52	0.160	0.005	3.2	3.195	0.450	0.265	0.061	3.295	0.121	0.188
Surface/production/train	7	0.114	0.02	0.2	0.18	0.065	0.162	0.092	2.255	0.121	0.368
Surface/production/truck	69	0.184	0.008	1.2	1.192	0.274	0.240	0.089	3.054	0.163	0.228
Surface/services/refuel	6	0.100	0.05	0.25	0.2	0.077	0.164	0.082	1.899	0.097	0.239
Surface/services/road maintenance	10	0.131	0.05	0.33	0.28	0.099	0.188	0.103	2.047	0.129	0.243
Surface/services/water cart	14	0.100	0.03	0.2	0.17	0.069	0.133	0.080	2.011	0.100	0.159
Surface/technical/supervisor	27	0.108	0.028	0.62	0.592	0.118	0.146	0.081	1.954	0.100	0.133
Surface/technical/technical	30	0.172	0.05	0.7	0.65	0.179	0.227	0.119	2.252	0.163	0.230
Underground/development/drill/ long hole	1	0.300	0.3	0.3	0	-	-	0.300	-	-	-
Underground/development/drill/jumbo	2	0.300	0.3	0.3	0	0.000	0.300	0.300	1.000	0.300	-
Underground/ground control/shotcrete	1	4.100	4.1	4.1	0	-	-	4.100	-	-	-
Underground/not otherwise classified	14	0.118	0.01	0.3	0.29	0.084	0.158	0.088	2.429	0.126	0.246
Underground/production/loader	2	0.125	0.05	0.2	0.15	0.106	0.599	0.100	2.665	0.125	-
Underground/production/truck	2	0.375	0.05	0.7	0.65	0.460	2.427	0.187	6.463	0.375	-

Figure 57: Average RD Exposure for Surface Metalliferous Mines by SEG

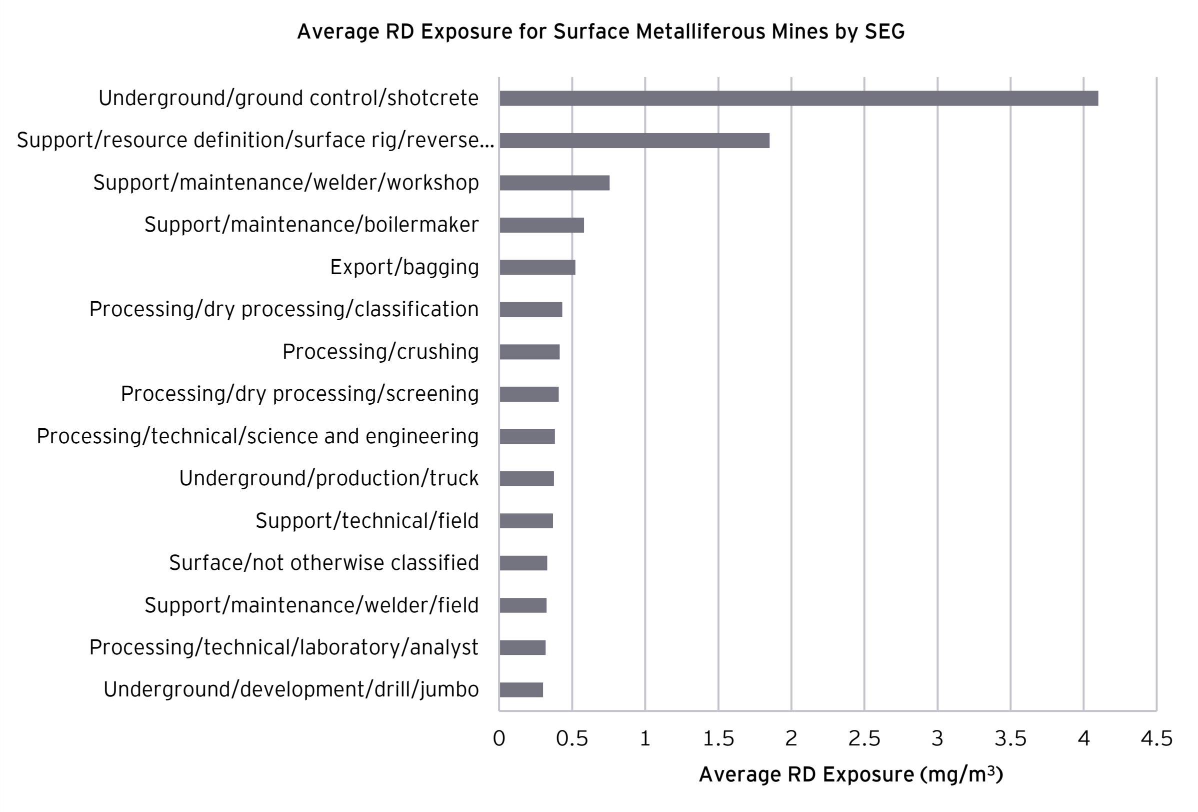


Table 100 shows the exposures by SEG for the underground metalliferous mines. All of the averages and geometric means are well below half of the OEL, but a few SEGs have UCLs or Log UCLs above due to the wide variation in exposures.

The largest number of samples in any SEG category is 201 in the "N/A" category which should prompt a review for adequacy of the current taxonomy to cover the SEGs and any education or guidance documents required for the mines or consultants in choosing the correct SEGs. For instance, there are 21 in the "N/A" category whose primary activity is "Operator Underground" where the SEG categories of "Underground/production/loader" and "Underground/production/truck" only have two samples each. There are also several primary activities relating to shotcreting in the N/A category, which should be reclassified into the proper category.

Table 100: RD Exposure for Underground Metalliferous Mines by SEG

Underground Mines	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	1	0.500	0.5	0.5	0	-	-	0.500	-	-	-
Export/ship loading	5	0.304	0.057	0.738	0.681	0.272	0.564	0.211	2.727	0.309	4.143
Export/truck-loading	13	0.085	0.017	0.217	0.2	0.048	0.109	0.073	1.812	0.086	0.128
N/A	201	0.289	0.02	2.353	2.333	0.363	0.331	0.161	3.014	0.294	0.353
Processing/crushing	104	0.367	0.01	2.28	2.27	0.409	0.434	0.226	2.829	0.386	0.489
Processing/dewatering	12	0.165	0.058	0.349	0.291	0.094	0.213	0.144	1.704	0.164	0.234
Processing/dry processing/classification	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Processing/dry processing/screening	23	0.241	0.05	0.738	0.688	0.182	0.307	0.190	2.043	0.242	0.340
Processing/not otherwise classified	55	0.124	0.011	0.8	0.789	0.159	0.160	0.074	2.621	0.117	0.159
Processing/technical/laboratory/analyst	14	1.236	0.05	8.5	8.45	2.674	2.501	0.239	5.171	0.766	5.492
Processing/technical/laboratory/sample prep	46	0.585	0.03	8	7.97	1.456	0.946	0.174	3.736	0.401	0.700
Processing/technical/science and engineering	13	0.053	0.014	0.111	0.097	0.025	0.065	0.047	1.681	0.053	0.074
Processing/wet processing/carbon-in-pulp	7	0.143	0.05	0.4	0.35	0.124	0.234	0.110	2.098	0.139	0.360
Processing/wet processing/flotation	23	0.145	0.021	0.621	0.6	0.131	0.192	0.110	2.077	0.142	0.202
Support/administration	6	0.135	0.05	0.3	0.25	0.097	0.215	0.110	1.991	0.134	0.368
Support/cleaners	8	0.085	0.031	0.228	0.197	0.072	0.133	0.066	2.072	0.082	0.184
Support/construction/buildings	3	0.117	0.05	0.2	0.15	0.076	0.245	0.100	2.000	0.117	-
Support/construction/plant	5	0.441	0.2	0.75	0.55	0.227	0.657	0.395	1.700	0.441	1.021
Support/fill/backfill	1	0.090	0.09	0.09	0	-	-	0.090	-	-	-
Support/fill/paste fill	26	0.164	0.01	0.7	0.69	0.148	0.214	0.118	2.411	0.171	0.261
Support/laundry	4	0.200	0.1	0.3	0.2	0.082	0.296	0.186	1.578	0.201	0.515
Support/logistics	32	0.140	0.013	0.619	0.606	0.136	0.181	0.096	2.412	0.139	0.202
Support/maintenance/boilermaker	45	0.562	0.016	3.989	3.973	0.803	0.763	0.274	3.507	0.584	0.983
Support/maintenance/electrical plant	79	0.194	0.017	2.112	2.095	0.291	0.249	0.111	2.696	0.179	0.233
Support/maintenance/fixed plant	166	0.286	0.001	3.123	3.122	0.479	0.347	0.138	3.218	0.271	0.337
Support/maintenance/mobile plant/breakdown	120	0.290	0.001	7.472	7.471	0.883	0.424	0.100	3.521	0.218	0.292
Support/maintenance/mobile plant/workshop	67	0.116	0.01	1.772	1.762	0.259	0.169	0.063	2.285	0.089	0.111
Support/maintenance/welder/field	2	1.250	0.1	2.4	2.3	1.626	8.511	0.490	9.461	1.250	-
Support/maintenance/welder/workshop	3	0.204	0.05	0.5	0.45	0.256	0.636	0.116	3.567	0.187	-
Support/not otherwise classified	31	0.180	0.01	2	1.99	0.397	0.301	0.076	3.107	0.139	0.244
Support/resource definition/surface rig/diamond	21	0.102	0.001	0.4	0.399	0.120	0.148	0.053	3.856	0.123	0.330
Support/resource definition/surface rig/reverse circulation	14	0.751	0.006	3.6	3.594	1.101	1.272	0.220	6.284	0.923	10.652
Support/resource definition/underground rig	37	0.310	0.02	1.352	1.332	0.339	0.404	0.191	2.754	0.313	0.477
Support/technical/field	62	0.189	0.015	1.22	1.205	0.192	0.230	0.134	2.271	0.186	0.234
Support/technical/office	7	0.121	0.05	0.5	0.45	0.168	0.245	0.077	2.378	0.105	0.361
Surface/development/blasting/drill	10	2.380	0.1	13	12.9	3.884	4.631	0.882	4.617	2.326	24.822
Surface/development/excavator	2	0.058	0.05	0.066	0.016	0.011	0.109	0.057	1.217	0.058	-
Surface/development/rubber tyred loader	1	0.230	0.23	0.23	0	-	-	0.230	-	-	-
Surface/development/scraper	1	0.200	0.2	0.2	0	-	-	0.200	-	-	-
Surface/development/truck	4	0.050	0.05	0.05	0	0.000	0.050	0.050	1.000	0.050	0.057
Surface/not otherwise classified	27	0.134	0.023	0.732	0.709	0.171	0.190	0.084	2.452	0.123	0.188
Surface/production/excavator	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Surface/production/rubber tyred loader	7	0.229	0.1	0.5	0.4	0.138	0.330	0.198	1.772	0.227	0.428
Surface/production/truck	14	0.070	0.001	0.152	0.151	0.045	0.091	0.040	5.084	0.125	0.859
Surface/services/road maintenance	8	0.094	0.05	0.2	0.15	0.062	0.135	0.079	1.797	0.092	0.164
Surface/services/water cart	2	0.173	0.1	0.246	0.146	0.103	0.634	0.157	1.890	0.173	-
Surface/technical/supervisor	4	0.073	0.05	0.143	0.093	0.047	0.128	0.065	1.691	0.072	0.238
Surface/technical/technical	6	0.270	0.05	0.6	0.55	0.197	0.432	0.208	2.344	0.278	1.199
Underground/development/charge up	132	0.427	0.001	3.8	3.799	0.499	0.499	0.275	2.855	0.473	0.585
Underground/development/drill/ long hole	62	0.374	0.05	1.3	1.25	0.303	0.438	0.265	2.410	0.387	0.497
Underground/development/drill/jumbo	175	0.299	0.001	2.524	2.523	0.286	0.335	0.210	2.508	0.320	0.372
Underground/development/drill/shaft sinking	10	0.324	0.05	0.8	0.75	0.232	0.458	0.246	2.323	0.336	0.764
Underground/ground control/shotcrete	86	0.833	0.01	3.4	3.39	0.834	0.983	0.431	3.811	1.035	1.530
Underground/ground control/strata stabilisation	20	0.481	0.061	1.3	1.239	0.342	0.613	0.372	2.160	0.492	0.747
Underground/not otherwise classified	152	0.297	0.01	1.75	1.74	0.337	0.343	0.180	2.815	0.306	0.371
Underground/production/loader	178	0.392	0.001	14.904	14.903	1.142	0.533	0.208	2.927	0.369	0.444
Underground/production/ring firer	24	0.260	0.05	0.688	0.638	0.167	0.318	0.201	2.239	0.273	0.405
Underground/production/truck	122	0.228	0.026	1.6	1.574	0.226	0.262	0.159	2.313	0.225	0.265
Underground/services/installation	187	0.488	0.001	5.8	5.799	0.632	0.564	0.302	2.806	0.513	0.608
Underground/services/refuel	43	0.366	0.001	1.837	1.836	0.363	0.459	0.217	3.703	0.493	0.876
Underground/services/water cart	37	0.225	0.026	0.781	0.755	0.185	0.277	0.163	2.341	0.230	0.319

Figure 58: Average RD Exposure for Underground Metalliferous Mines by SEG

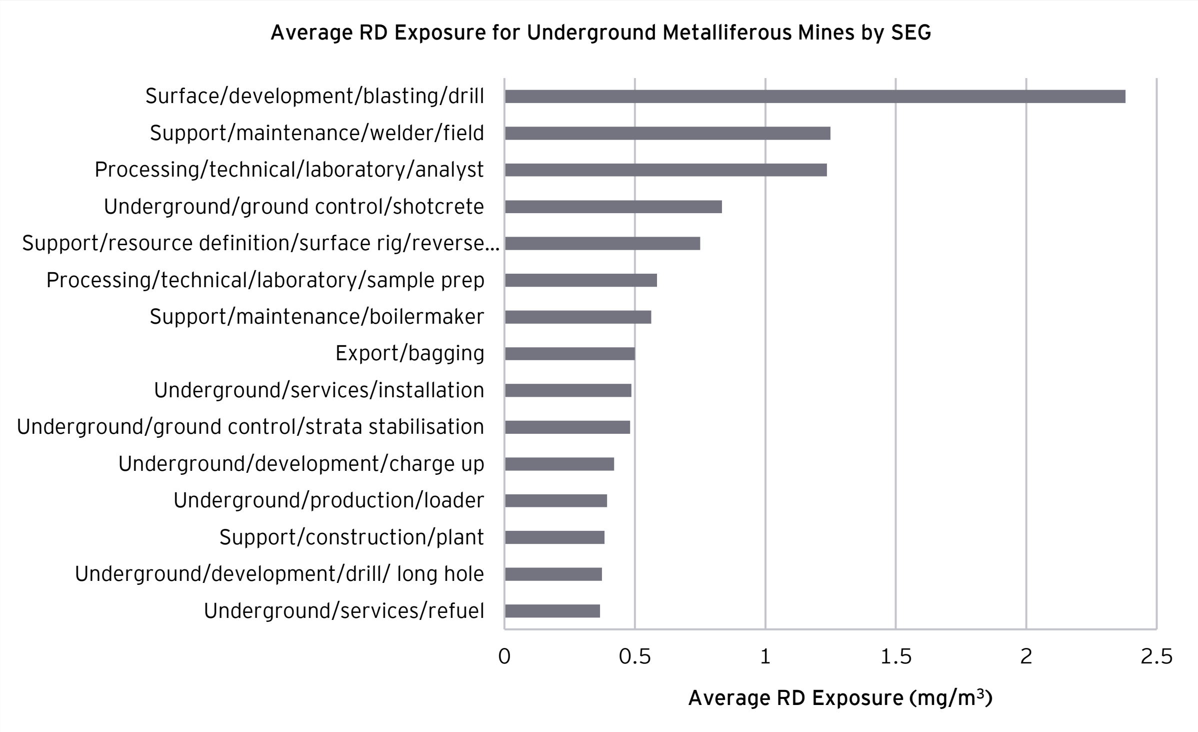


Table 101 and Figure 59 show the RD exposure for the Quarry SEGs. The majority of these SEGs are well below half the OEL except for the cleaner. There are only 4 samples from cleaners, but the 19.54 mg/m^3 level is concerning, especially as the comments for that sample indicate that it is representative of the workers exposure.

Table 101: RD Exposure for Quarry SEGs

Metalliferous - Quarry	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/bagging	1	0.530	0.53	0.53	0	-	-	0.530	-	-	-
Export/truck-loading	93	0.103	0.005	1.44	1.435	0.184	0.135	0.056	2.744	0.093	0.119
N/A	155	0.358	0.01	5.21	5.2	0.732	0.455	0.147	3.512	0.320	0.413
Processing/crushing	277	0.383	0.02	14.374	14.354	0.935	0.476	0.205	2.791	0.346	0.397
Processing/dry processing/classification	1	0.230	0.23	0.23	0	-	-	0.230	-	-	-
Processing/dry processing/screening	25	0.228	0.01	2.11	2.1	0.433	0.376	0.085	4.112	0.216	0.555
Processing/not otherwise classified	40	0.225	0.02	1.36	1.34	0.295	0.304	0.123	3.015	0.222	0.350
Processing/technical/laboratory/analyst	32	0.160	0.01	1.2	1.19	0.230	0.229	0.094	2.667	0.149	0.231
Processing/technical/laboratory/sample prep	43	0.142	0.006	1.06	1.054	0.174	0.187	0.090	2.649	0.143	0.205
Processing/wet processing/screening	9	0.112	0.021	0.39	0.369	0.119	0.186	0.077	2.418	0.107	0.285
Support/administration	99	0.069	0.005	0.49	0.485	0.075	0.081	0.050	2.121	0.067	0.078
Support/cleaners	4	5.218	0.05	19.54	19.49	9.553	16.458	0.790	11.629	4.255	126068465329
Support/construction/plant	5	0.153	0.043	0.38	0.337	0.149	0.295	0.103	2.676	0.149	1.825
Support/logistics	15	0.116	0.01	0.48	0.47	0.126	0.173	0.072	2.796	0.117	0.261
Support/maintenance/boilermaker	98	0.771	0.028	6.68	6.652	1.132	0.961	0.411	3.060	0.760	1.000
Support/maintenance/electrical plant	8	0.584	0.04	1.94	1.9	0.699	1.052	0.241	4.746	0.630	14.469
Support/maintenance/fixed plant	198	0.681	0.02	11.6	11.58	1.200	0.822	0.318	3.337	0.653	0.804
Support/maintenance/mobile plant/breakdown	29	0.325	0.02	2.01	1.99	0.453	0.468	0.181	2.833	0.303	0.506
Support/maintenance/mobile plant/workshop	33	0.248	0.03	1.33	1.3	0.302	0.337	0.138	2.898	0.237	0.386
Support/maintenance/welder/field	7	0.274	0.06	0.9	0.84	0.295	0.491	0.185	2.501	0.262	1.031
Support/maintenance/welder/workshop	26	0.578	0.08	3.2	3.12	0.662	0.800	0.370	2.583	0.567	0.913
Support/not otherwise classified	34	0.126	0.01	0.51	0.5	0.134	0.165	0.074	2.923	0.129	0.209
Support/technical/field	40	0.156	0.03	0.83	0.8	0.179	0.203	0.101	2.393	0.146	0.202
Support/technical/office	13	0.062	0.01	0.11	0.1	0.029	0.077	0.054	1.884	0.065	0.100
Surface/development/blasting/charge up	5	0.072	0.05	0.11	0.06	0.024	0.095	0.069	1.362	0.072	0.105
Surface/development/blasting/drill	57	0.143	0.01	1.83	1.82	0.266	0.202	0.082	2.486	0.123	0.162
Surface/development/dozer	12	0.117	0.05	0.27	0.22	0.077	0.157	0.097	1.888	0.116	0.184
Surface/development/excavator	43	0.208	0.02	1.33	1.31	0.298	0.284	0.106	3.078	0.195	0.306
Surface/development/rubber tyred loader	44	0.168	0.01	1.33	1.32	0.226	0.225	0.097	2.840	0.164	0.243
Surface/development/scraper	1	0.020	0.02	0.02	0	-	-	0.020	-	-	-
Surface/development/truck	20	0.261	0.03	1.93	1.9	0.479	0.446	0.108	3.222	0.204	0.455
Surface/not otherwise classified	140	0.320	0.005	3.33	3.325	0.474	0.386	0.156	3.348	0.321	0.413
Surface/production/excavator	213	0.152	0.005	2	1.995	0.253	0.180	0.085	2.657	0.136	0.158
Surface/production/rubber tyred loader	342	0.131	0.005	2.7	2.695	0.204	0.150	0.080	2.575	0.125	0.139
Surface/production/train	23	0.933	0.05	7.4	7.35	1.738	1.555	0.315	4.018	0.768	2.034
Surface/production/truck	268	0.158	0.005	5.21	5.205	0.346	0.193	0.094	2.514	0.143	0.161
Surface/services/refuel	4	0.538	0.05	1.88	1.83	0.896	1.592	0.175	5.255	0.422	24421.127
Surface/services/road maintenance	9	0.292	0.03	1.59	1.56	0.503	0.604	0.121	3.645	0.242	1.659
Surface/services/water cart	68	0.150	0.02	0.89	0.87	0.155	0.181	0.100	2.432	0.147	0.187
Surface/technical/supervisor	123	0.168	0.01	1.2	1.19	0.226	0.201	0.101	2.512	0.153	0.184
Surface/technical/technical	10	0.144	0.02	0.39	0.37	0.125	0.216	0.098	2.650	0.148	0.420

Figure 59: Average RD Exposure for Quarry by SEG

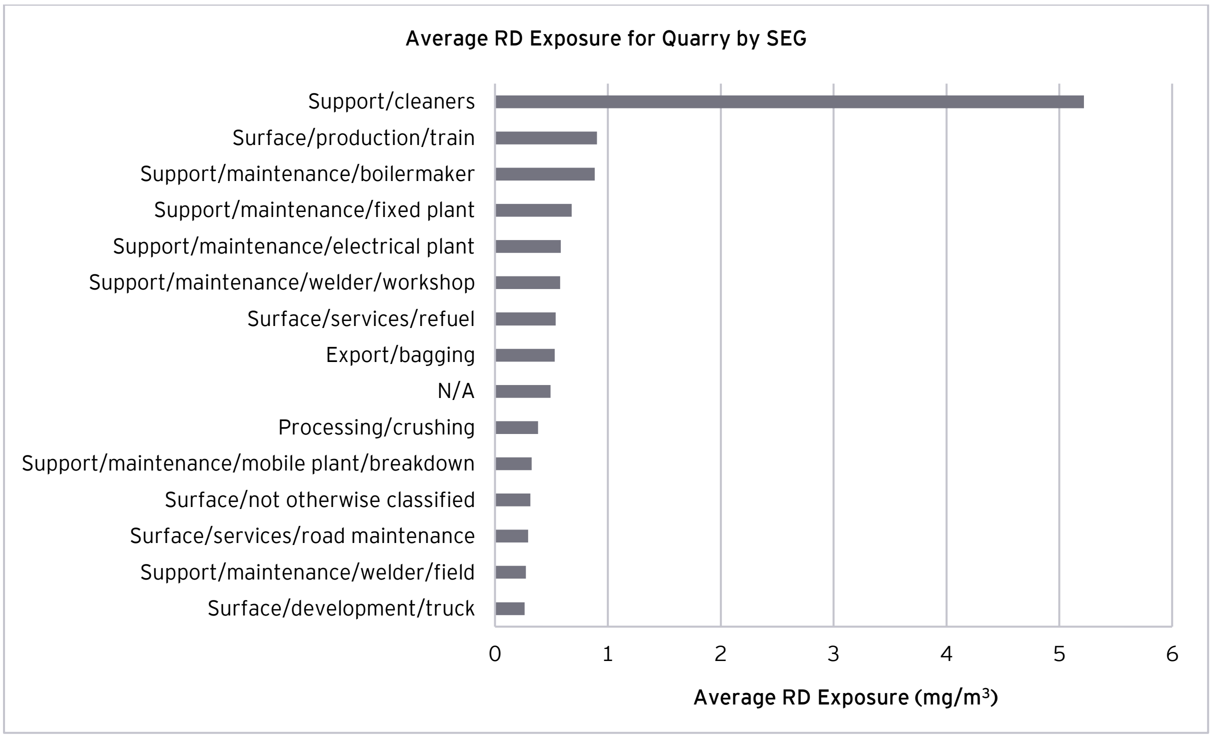


Table 102 and Figure 60 show the RD Exposures for the Mineral Processing SEGs. All of the SEGs have a Geometric mean below half the OEL and all but two have an average below half the OEL.

These SEGs should be reviewed for applicability to the mine type. While some activities such as dozer operation could take place in the mine as well as at the mineral processing facility there are others such as underground long hole and jumbo drilling that are clearly not a mineral processing task.

Table 102: RD Exposure for Mineral Processing SEGs

Mineral Processing SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/truck-loading	2	0.100	0.1	0.1	0	0.000	0.100	0.100	1.000	0.100	-
Processing/crushing	57	0.250	0.045	3.9	3.855	0.516	0.365	0.153	2.224	0.208	0.262
Processing/dewatering	9	0.570	0.047	3.1	3.053	0.965	1.169	0.248	3.691	0.504	3.586
Processing/dry processing/screening	7	0.643	0.001	3.266	3.265	1.173	1.505	0.125	12.561	1.101	19960.722
Processing/not otherwise classified	50	0.404	0.046	7.104	7.058	1.046	0.652	0.140	3.460	0.294	0.475
Processing/smelting	86	0.588	0.001	26.407	26.406	2.845	1.098	0.173	3.430	0.365	0.514
Processing/technical/laboratory/sample prep	7	0.486	0.05	2.3	2.25	0.817	1.086	0.189	4.053	0.407	8.194
Processing/technical/science and engineering	11	0.381	0.023	3.278	3.255	0.964	0.908	0.102	3.759	0.216	1.115
Processing/wet processing/cutting	7	0.386	0.05	1.4	1.35	0.504	0.756	0.185	3.702	0.364	5.100
Processing/wet processing/flotation	11	0.183	0.05	0.5	0.45	0.147	0.263	0.140	2.155	0.182	0.349
Processing/wet processing/heap leach	5	0.120	0.05	0.4	0.35	0.157	0.269	0.076	2.534	0.105	0.998
Processing/wet processing/screening	1	0.050	0.05	0.05	0	-	-	0.050	-	-	-
Processing/wet processing/solvent extraction	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Support/cleaners	7	0.170	0.042	0.771	0.729	0.269	0.367	0.087	2.908	0.138	0.838
Support/construction/buildings	1	0.126	0.126	0.126	0	-	-	0.126	-	-	-
Support/fill/paste fill	1	0.050	0.05	0.05	0	-	-	0.050	-	-	-
Support/laundry	11	0.189	0.05	1.079	1.029	0.303	0.355	0.105	2.627	0.158	0.405
Support/logistics	1	0.045	0.045	0.045	0	-	-	0.045	-	-	-
Support/maintenance/boilermaker	26	0.597	0.028	5.677	5.649	1.246	1.015	0.203	3.916	0.484	1.148
Support/maintenance/electrical plant	42	0.130	0.001	0.86	0.859	0.174	0.176	0.072	3.193	0.138	0.223
Support/maintenance/fixed plant	33	0.420	0.027	3.649	3.622	0.790	0.653	0.160	3.572	0.345	0.663
Support/maintenance/mobile plant/breakdown	1	0.050	0.05	0.05	0	-	-	0.050	-	-	-
Support/maintenance/mobile plant/workshop	9	0.101	0.05	0.3	0.25	0.079	0.150	0.084	1.818	0.098	0.167
Support/maintenance/welder/field	1	0.554	0.554	0.554	0	-	-	0.554	-	-	-
Support/not otherwise classified	12	3.391	0.05	28.322	28.272	8.163	7.622	0.309	9.344	2.263	146.250
Support/technical/field	7	0.057	0.05	0.1	0.05	0.019	0.071	0.055	1.300	0.057	0.071
Support/technical/office	1	0.050	0.05	0.05	0	-	-	0.050	-	-	-
Surface/development/blasting/drill	13	3.081	0.05	14	13.95	4.580	5.345	1.179	4.627	3.242	20.485
Surface/development/dozer	2	0.080	0.06	0.1	0.04	0.028	0.206	0.077	1.435	0.080	-
Surface/development/excavator	2	0.075	0.05	0.1	0.05	0.035	0.233	0.071	1.633	0.075	-
Surface/development/rubber tyred loader	3	0.050	0.05	0.05	0	0.000	0.050	0.050	1.000	0.050	-
Surface/development/truck	2	0.045	0.04	0.05	0.01	0.007	0.077	0.045	1.171	0.045	-
Surface/production/excavator	7	0.151	0.05	0.6	0.55	0.199	0.298	0.098	2.365	0.133	0.456
Surface/production/rubber tyred loader	7	0.094	0.05	0.287	0.237	0.089	0.159	0.073	1.989	0.089	0.206
Surface/production/truck	3	0.083	0.05	0.1	0.05	0.029	0.132	0.079	1.492	0.084	-
Surface/technical/supervisor	6	0.063	0.04	0.1	0.06	0.029	0.087	0.058	1.533	0.063	0.102
Surface/technical/technical	5	0.258	0.05	0.7	0.65	0.258	0.504	0.176	2.692	0.254	3.203
Underground/development/charge up	3	0.433	0.3	0.6	0.3	0.153	0.691	0.416	1.417	0.433	-
Underground/development/drill/ long hole	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Underground/development/drill/jumbo	4	0.250	0.2	0.4	0.2	0.100	0.368	0.238	1.414	0.249	0.457
Underground/not otherwise classified	2	0.200	0.2	0.2	0	0.000	0.200	0.200	1.000	0.200	-
Underground/production/loader	1	0.200	0.2	0.2	0	-	-	0.200	-	-	-
Underground/production/truck	1	0.200	0.2	0.2	0	-	-	0.200	-	-	-
Underground/services/installation	2	0.450	0.4	0.5	0.1	0.071	0.766	0.447	1.171	0.450	-

Figure 60: Average RD Exposure for Processing by SEG

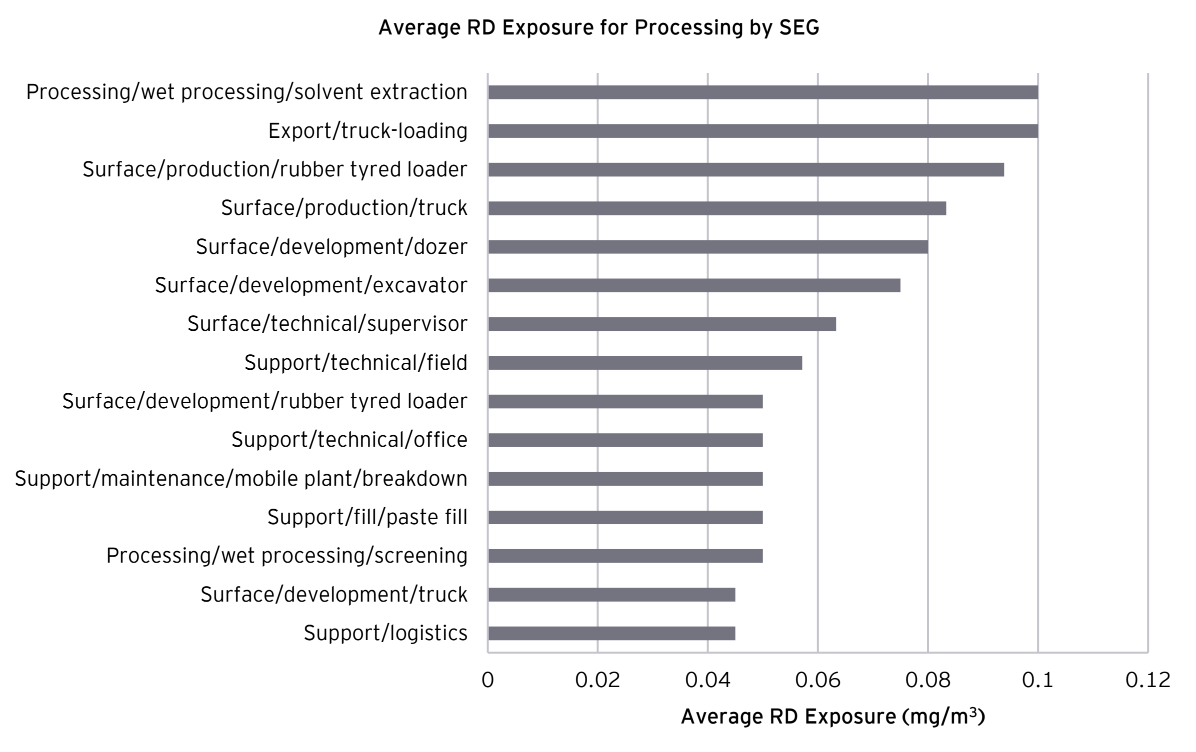


Table 103 and Figure 61 show the RD exposure for the Quarry - Group SEGs. There are very few samples for each of these SEGs making it difficult to generalise the sector. Of the samples that are taken the exposure levels are extremely low.

Table 103: RD Exposure for Quarry - Group by SEG

Quarry - Group	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Export/truck-loading	3	0.090	0.03	0.13	0.1	0.053	0.179	0.075	2.232	0.093	-
Processing/crushing	8	0.169	0.03	0.4	0.37	0.113	0.244	0.136	2.139	0.174	0.411
Support/technical/field	2	0.065	0.05	0.08	0.03	0.021	0.160	0.063	1.394	0.065	-
Surface/development/dozer	5	0.070	0.02	0.12	0.1	0.038	0.106	0.060	1.995	0.072	0.266
Surface/development/rubber tyred loader	1	0.090	0.09	0.09	0	-	-	0.090	-	-	-
Surface/not otherwise classified	7	0.107	0.05	0.3	0.25	0.089	0.172	0.087	1.910	0.104	0.222
Surface/production/excavator	2	0.260	0.02	0.5	0.48	0.339	1.775	0.100	9.739	0.260	-
Surface/production/rubber tyred loader	8	0.104	0.02	0.26	0.24	0.075	0.154	0.080	2.294	0.107	0.290
Surface/services/water cart	1	0.010	0.01	0.01	0	-	-	0.010	-	-	-
Surface/technical/supervisor	2	0.115	0.03	0.2	0.17	0.120	0.652	0.077	3.825	0.115	-

Figure 61: Average RD Exposure for Quarry - Group by SEG

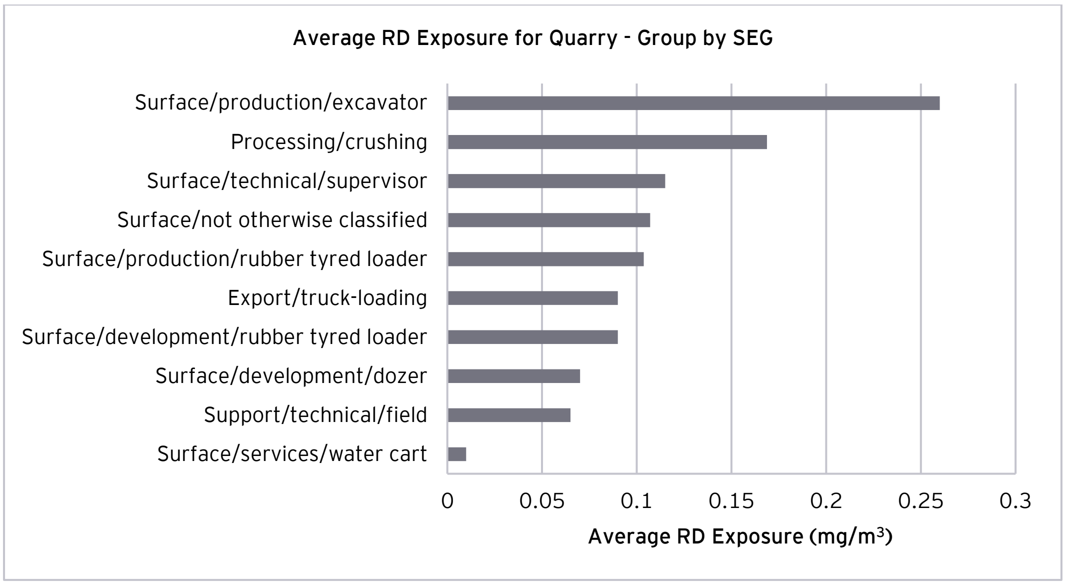


Table 104 and Figure 62 show the RD exposure for the Exploration SEGs. All of these SEGs have fewer than 10 samples each making it difficult to generalise the sector. Of the samples that are taken the exposure levels are extremely low. The underground services installation and reverse circulation surface rigs have the highest maximum exposures of the sector.

Table 104: RD Exposure for Exploration by SEG

Exploration SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/technical/laboratory/sample prep	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Processing/wet processing/flotation	3	0.067	0.05	0.1	0.05	0.029	0.115	0.063	1.492	0.066	-
Support/logistics	2	0.075	0.05	0.1	0.05	0.035	0.233	0.071	1.633	0.075	-
Support/maintenance/electrical plant	2	0.150	0.1	0.2	0.1	0.071	0.466	0.141	1.633	0.150	-
Support/maintenance/fixed plant	2	0.200	0.1	0.3	0.2	0.141	0.831	0.173	2.175	0.200	-
Support/maintenance/mobile plant/workshop	1	1.400	1.4	1.4	0	-	-	1.400	-	-	-
Support/not otherwise classified	3	0.067	0.05	0.1	0.05	0.029	0.115	0.063	1.492	0.066	-
Support/resource definition/surface rig/diamond	2	0.050	0.05	0.05	0	0.000	0.050	0.050	1.000	0.050	-
Support/resource definition/surface rig/reverse circulation	9	0.772	0.05	2.4	2.35	0.754	1.239	0.461	3.311	0.842	4.474
Support/technical/field	4	0.238	0.05	0.6	0.55	0.250	0.531	0.157	2.885	0.231	20.249
Surface/production/rubber tyred loader	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Surface/production/truck	6	0.133	0.05	0.3	0.25	0.098	0.214	0.107	2.063	0.132	0.398
Surface/services/road maintenance	1	0.050	0.05	0.05	0	-	-	0.050	-	-	-
Surface/technical/technical	2	0.050	0.05	0.05	0	0.000	0.050	0.050	1.000	0.050	-
Underground/development/charge up	4	0.375	0.2	0.6	0.4	0.171	0.576	0.346	1.590	0.375	0.987
Underground/development/drill/ long hole	3	0.700	0.5	0.9	0.4	0.200	1.037	0.680	1.343	0.700	-
Underground/not otherwise classified	1	0.200	0.2	0.2	0	-	-	0.200	-	-	-
Underground/production/loader	3	0.200	0.1	0.4	0.3	0.173	0.492	0.159	2.226	0.194	-
Underground/production/truck	3	0.300	0.1	0.4	0.3	0.173	0.592	0.252	2.226	0.309	-
Underground/services/installation	1	2.000	2	2	0	-	-	2.000	-	-	-

Figure 62: Average RD Exposure for Metalliferous Mine Exploration by SEG

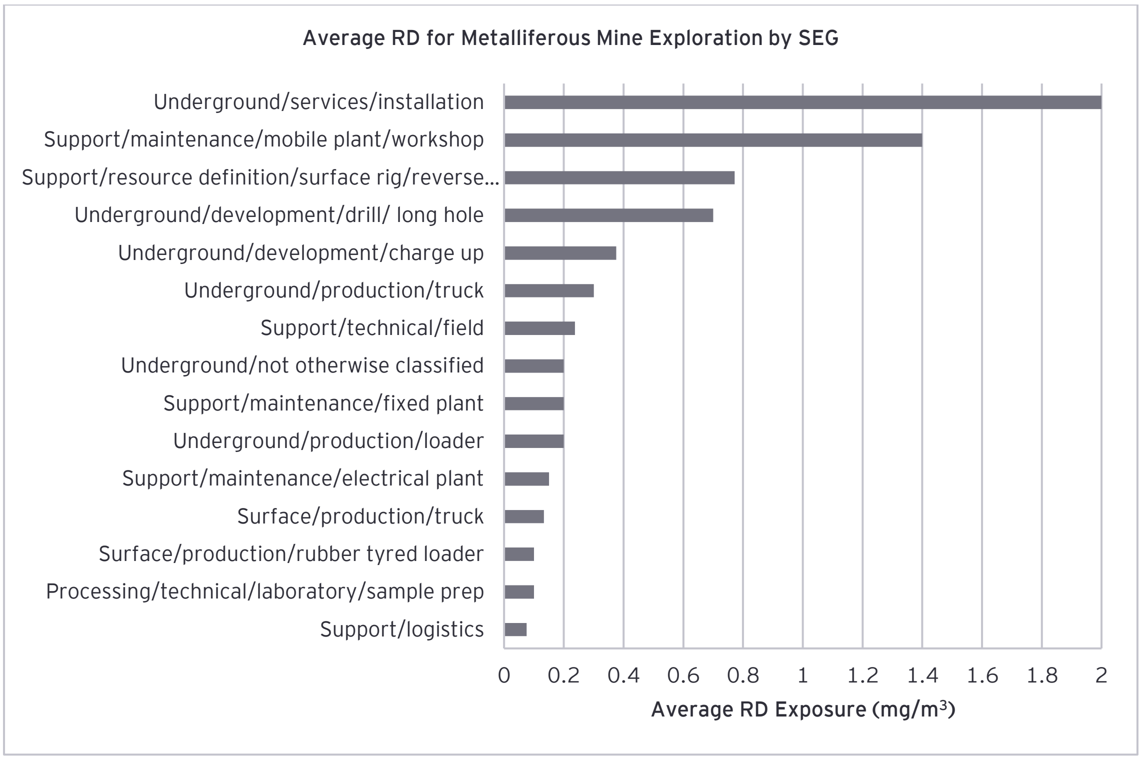


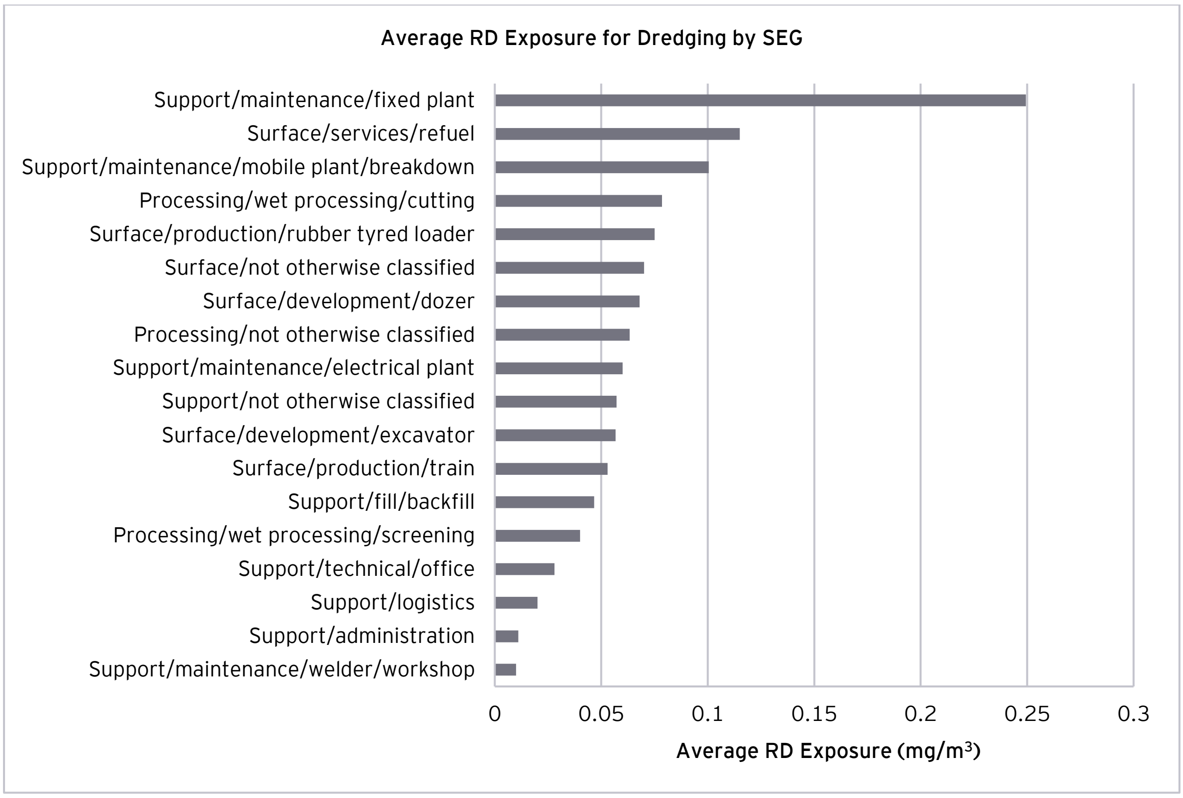
Table 105 and Figure 63 show the SEGs for the dredging operations. The SEG with the highest average exposure is support/maintenance/fixed plant at 0.25 mg/m^3. All the SEGs have averages and geometric means below the half the OEL.

These SEGs should be reviewed for adequacy of the current taxonomy and any education or guidance documents required for the mines or consultants in choosing the correct SEGs. The "not otherwise classified" SEGs for processing, support and surface account for 24 samples or 37% of the entire sample set.

Table 105: RD Exposure for Dredging Operation SEGs

Dredging Operations SEGs	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/not otherwise classified	3	0.063	0.05	0.08	0.03	0.015	0.089	0.062	1.267	0.063	-
Processing/wet processing/cutting	2	0.079	0.068	0.089	0.021	0.015	0.145	0.078	1.210	0.078	-
Processing/wet processing/screening	1	0.040	0.04	0.04	0	-	-	0.040	-	-	-
Support/administration	2	0.011	0.01	0.012	0.002	0.001	0.017	0.011	1.138	0.011	-
Support/fill/backfill	3	0.047	0.02	0.07	0.05	0.025	0.089	0.041	1.912	0.047	-
Support/logistics	1	0.020	0.02	0.02	0	-	-	0.020	-	-	-
Support/maintenance/electrical plant	4	0.060	0.02	0.11	0.09	0.042	0.110	0.048	2.233	0.060	0.819
Support/maintenance/fixed plant	8	0.249	0.005	1.49	1.485	0.505	0.588	0.073	5.007	0.203	5.761
Support/maintenance/mobile plant/breakdown	2	0.101	0.059	0.142	0.083	0.059	0.363	0.092	1.861	0.100	-
Support/maintenance/welder/workshop	1	0.010	0.01	0.01	0	-	-	0.010	-	-	-
Support/not otherwise classified	13	0.057	0.039	0.11	0.071	0.022	0.068	0.054	1.385	0.057	0.068
Support/technical/office	2	0.028	0.01	0.046	0.036	0.025	0.142	0.021	2.942	0.028	-
Surface/development/dozer	6	0.068	0.01	0.13	0.12	0.045	0.105	0.051	2.602	0.073	0.442
Surface/development/excavator	3	0.057	0.03	0.09	0.06	0.031	0.108	0.051	1.733	0.057	-
Surface/not otherwise classified	8	0.070	0.04	0.13	0.09	0.035	0.093	0.064	1.539	0.070	0.101
Surface/production/rubber tyred loader	2	0.075	0.03	0.12	0.09	0.064	0.359	0.060	2.665	0.075	-
Surface/production/train	3	0.053	0.05	0.058	0.008	0.004	0.060	0.053	1.084	0.053	-
Surface/services/refuel	1	0.115	0.115	0.115	0	-	-	0.115	-	-	-

Figure 63: Average RD Exposure for Dredging by SEG



Only 3 samples were taken in the surface alluvial gold sector which are shown in Table 106 and Figure 64

Table 106: RD Exposure for Surface Alluvial Gold by SEG

Surface Alluvial Gold	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/crushing	1	1.030	1.03	1.03	0	-	-	1.030	-	-	-
Processing/wet processing/screening	1	0.130	0.13	0.13	0	-	-	0.130	-	-	-
Surface/production/excavator	1	0.320	0.32	0.32	0	-	-	0.320	-	-	-

Figure 64: Average RD Exposure for Surface Alluvial by SEG

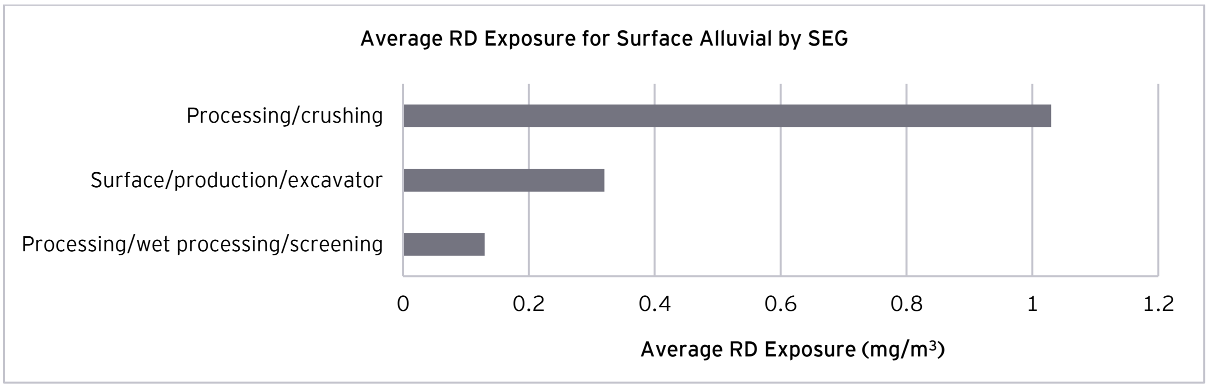


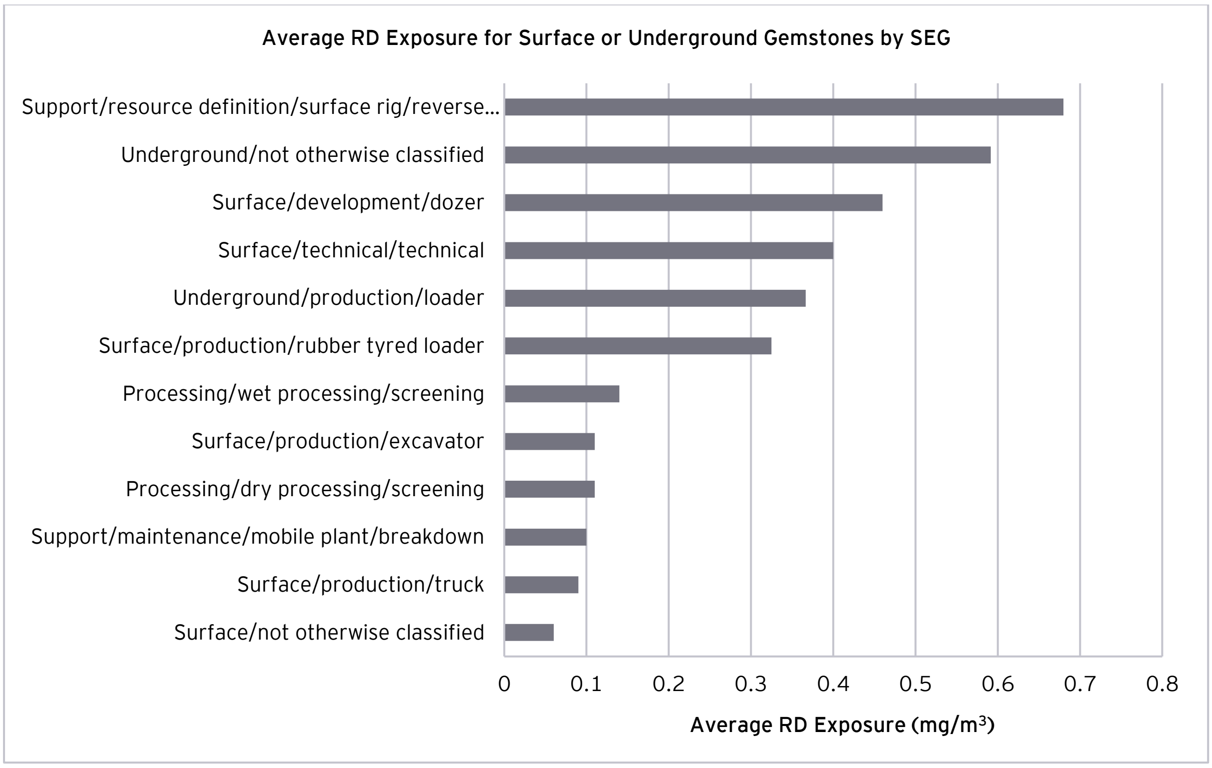
Table 107 and Figure 65 show the RD exposures for the surface and underground Gemstone SEGs. There are only a small number of samples taken for this sector. All of the average and geometric means are below half of the OEL. The maximum for underground/not otherwise classified is 2.5 mg/m^3 which put the Log UCL above half the OEL.

These SEGs should be reviewed for adequacy of the current taxonomy and any education or guidance documents required for the mines or consultants in choosing the correct SEGs. The "not otherwise classified" SEGs for surface and underground account for 15 samples or 31% of the entire sample set.

Table 107: RD Exposure for Surface or Underground Gemstone SEGs

Surface or Underground Gemstones	No of Samples	Normal Parametric Mean	Minimum	Maximum	Range	Std Dev	Normal Parametric 95% UCL	Geometric Mean	Geometric Std Dev	Lognormal Parametric MVUE	Lognormal Parametric 95% UCL
Processing/dry processing/screening	1	0.110	0.11	0.11	0	-	-	0.110	-	-	-
Processing/wet processing/screening	1	0.140	0.14	0.14	0	-	-	0.140	-	-	-
Support/maintenance/mobile plant/breakdown	1	0.100	0.1	0.1	0	-	-	0.100	-	-	-
Support/resource definition/surface rig/reverse circulation	1	0.680	0.68	0.68	0	-	-	0.680	-	-	-
Surface/development/dozer	2	0.460	0.16	0.76	0.6	0.424	2.354	0.349	3.010	0.460	-
Surface/not otherwise classified	2	0.060	0.01	0.11	0.1	0.071	0.376	0.033	5.450	0.060	-
Surface/production/excavator	3	0.110	0.02	0.16	0.14	0.078	0.242	0.078	3.262	0.119	-
Surface/production/rubber tyred loader	2	0.325	0.29	0.36	0.07	0.049	0.546	0.323	1.165	0.325	-
Surface/production/truck	1	0.090	0.09	0.09	0	-	-	0.090	-	-	-
Surface/technical/technical	1	0.400	0.4	0.4	0	-	-	0.400	-	-	-
Underground/not otherwise classified	12	0.592	0.04	2.5	2.46	0.723	0.967	0.304	3.583	0.618	2.548
Underground/production/loader	12	0.367	0.11	0.72	0.61	0.218	0.480	0.306	1.907	0.369	0.590

Figure 65: Average RD Exposure for Surface or Underground Gemstones by SEG



Appendix I VOCs workplace exposure standards from various jurisdictions

	CMSHR Sched 6		Safe Work Aus		proposed	OSHA		NIOSH		ACGIH		Comment
	Long-term	Maximum exposure						TWA	STEL	TWA	STEL	
Acetaldehyde	100 ppmv	150 ppmv	20 pppmv	50 ppmv	20 ppmv peak	200 ppmv		100 ppmv	150 ppmv	25 ppmv		POT CARCINOGEN
Formaldehyde	1 ppmv	2 ppmv	1 ppmv	2 ppmv		0.75 ppmv	2 ppmv	0.016 ppmv	0.1 ppmv	0.1 ppmv	0.3 ppmv	POT CARCINOGEN
Acetic Acid			10 ppmv	15 ppmv		10 ppmv		10 ppmv	15 ppmv	10 ppmv	15 ppmv	
Acetone			500 ppmv	1000 ppmv	250 ppmv	1000 ppmv		250 ppmv		250 ppmv	500 ppmv	
Allyl alcohol			2 ppmv	4 ppmv	1 ppmv	2 ppmv		2 ppmv	4ppmv	0.5 ppmv		
Ethanol			1000 ppmv		200 ppmv 800 ppmv stel	1000 ppmv		1000 ppmv			1000 ppmv	
Methanol			200 ppmv	250 ppmv	100 ppmv	200 ppmv		200 ppmv	250 ppmv	200 ppmv	250 ppmv	
Benzene			1 ppmv		0.2 ppmv	10 ppmv	25 ppmv	0.1 ppmv	1 ppmv	0.4 ppmv	2.5 ppmv	carcinogen
Naphthalene			10 ppmv	15 ppmv	10 ppmv	10 ppmv		10 ppmv		10 ppmv		
Toluene			50 ppmv	150 ppmv	20 ppmv peak	200 ppmv	300 ppmv			25 ppmv	100 ppmv	
Phenol			1 ppmv			5 ppmv		5 ppmv		5 ppmv		
Cyclohexane			100 ppmv	300 ppmv	no stel	300 ppmv		300 ppmv		100 ppmv		
Ethyl Acetate			200 ppmv	400 stel		400 ppmv		400 ppmv		400 ppmv		
non nHexane			500 ppmv	1000 ppmv		500 ppmv						

	CMSHR Sched 6		Safe Work Aus		proposed	OSHA		NIOSH		ACGIH		Comment
	Long-term	Maximum exposure						TWA	STEL	TWA	STEL	
nHexane			20 ppmv		50 ppmv			50 ppmv		50 ppmv		
Octane			300 ppmv	375 ppmv		500 ppmv		75 ppmv	385 ppmv	300 ppmv		
Propane						1000 ppmv		1000 ppmv				simple asphyxiant
Benzo(a) pyrene					0.13 µg/m^3	0.2 mg/m^3		0.1 mg/m^3		0.2 mg/m^3		pot carcinogen
54 % Chlorine			0.5 mg/m^3	1 mg/m^3		0.5 mg/m^3		0.001 mg/m^3				pot carcinogen
42 % Chlorine			1 mg/m^3	2 mg/m^3								
Petroleum distillate			900 mg/m^3		add peak 1480 mg/m^3	2000 mg/m^3		350 mg/m^3	1800 mg/m^3	1590 mg/m^3		
Mineral oils	5 mg/m^3		5 mg/m^3									
Vegetable oils	10 mg/m^3		10 mg/m^3		not recommended							
Pyridine			5 ppmv		1 ppmv	5 ppmv		5ppmv		1 ppmv		
Trichloro-ethylene			10 ppmv	40 ppmv		100 ppmv	200 ppmv	25 ppmv		10 ppmv	25 ppmv	POT CARCINOGEN
methylene chloride			50 ppmv			25 ppmv	125 ppmv	25 ppmv		50 ppmv		POT CARCINOGEN

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