SafeWork NSW

NSW GOVERNMENT

Tunnels and shafts in construction

Code of practice

August 2026

Editorial note

This Code of practice has been developed by SafeWork NSW and has been approved under section 274 of the NSW *Work Health and Safety Act 2011*. Notice of that approval was published in the NSW Government Gazette referring to this Code of practice as Tunnels and shafts in construction on Friday 28 August 2026. This Code of practice commenced on 28 August 2026. It replaces the 2006 Tunnels and shafts in construction Code of Practice.

This Code of practice (this Code) should be read in its entirety.

When reading this Code, please be aware that any reference to:

- the 'Work Health and Safety Act' refers to the *Work Health and Safety Act 2011* (NSW), or any successor legislation,
- the 'Work Health and Safety Regulation' refers to the *Work Health and Safety Regulation 2025* (NSW), or any successor regulation,
- a code of practice refers to the relevant NSW Code of practice, or any successor code of practice.

This Code may contain references to relevant withdrawn or superseded Australian Standards or Australian/New Zealand Standards.

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SafeWork NSW wishes to acknowledge the contribution and collaboration of industry and social partners through the public comment period and technical development of this Code.

Additionally, the cooperation of other WHS regulators and Safe Work Australia is acknowledged for aligning materials where appropriate, particularly from Safe Work Australia's Guidance Material.

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Foreword

What is an approved Code of practice?

This Code of Practice (this Code) on Tunnels and shafts in construction is an approved code of practice under section 274 of the *Work Health and Safety Act 2011* (the WHS Act).

An approved code of practice provides practical guidance on how to achieve the standards of work health and safety required under the WHS Act and the *Work Health and Safety Regulation* (the WHS Regulation), including effective ways to identify hazards and manage risks.

Under section 26A of the WHS Act, a person conducting a business or undertaking (PCBU) must comply with an approved code of practice or follow another method to manage hazards and risks, such as a technical or industry standard that provides an equivalent or higher standard of health and safety than the standard required in this Code.

A code of practice can assist anyone who has a duty of care in the circumstances described in the code of practice. Following an approved code of practice will assist a duty holder to achieve compliance with health and safety duties under the WHS Act and WHS Regulation, in relation to the subject matter of the code of practice. Like regulations, codes of practice deal with particular issues and may not cover all relevant hazards or risks. The health and safety duties require duty holders to consider all risks associated with work, not only those for which regulations and codes of practice exist.

Codes of practice are admissible in court proceedings under the WHS Act and WHS Regulation. Courts may regard a code of practice as evidence of what is known about a hazard, risk, risk assessment or risk control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code of practice relates. For further information see SafeWork NSW's guidance on *Reasonably practicable*.

An inspector may refer to an approved code of practice when issuing an improvement notice or prohibition notice. This may include issuing an improvement notice to a PCBU for a contravention of section 26A of the WHS Act for failing to comply with a code of practice where equivalent or higher standards of work health and safety have not been demonstrated.

Scope and application

This Code is intended to be read by a PCBU. It provides practical guidance to PCBUs on how to manage risks to health and safety associated with the construction of a tunnel. Other approved codes of practice must also be referenced for further guidance and managing the risk of specific hazards. Where international standards or guidance are referenced, they are provided as examples of recognised practice.

This Code may be a useful reference for other persons interested in the duties under the WHS Act and WHS Regulation.

This Code applies to all types of work and all workplaces covered by the WHS Act where tunnelling work is undertaken. This includes work involving planning, design and construction of tunnels and shafts, their excavation, ground support and lining, mechanical and electrical plant installation and commissioning. This Code also applies when maintaining, repairing and renovating tunnels.

This Code does not apply to mines and quarries intended for purposes of extracting minerals. Mining is addressed in specific work health and safety mining legislation.

How to use this Code of practice

This Code includes various references to the legal requirements under the WHS Act and WHS Regulation. These references are included for convenience only and should not be relied on in place of the full text of the WHS Act or WHS Regulation.

The words ‘must’, ‘requires’ or ‘mandatory’ indicate a legal requirement exists that must be complied with.

The word ‘should’ is used to identify the standard required in this Code. PCBUs can only manage the identified hazard or risk in a different way if doing so provides an equivalent or higher standard of work health and safety than the standard required in this Code.

The word ‘may’ is used to indicate an optional course of action.

1. Introduction

1.1 Health and safety risk management in tunnelling and underground construction

In comparison to other forms of construction, underground construction is highly complex. This complexity arises from the use of highly specialised construction plant and equipment in typically constrained working areas and from variable, uncertain ground conditions[1] and behaviour.

Managing and controlling the safety of a tunnel construction site and maintaining the health of workers, engineers, managers and frontline supervisors required for construction, requires the effective management of risks, the implementation of effective control measures, clear allocation of responsibilities, consultation, cooperation and coordination, good communication and clearly defined objectives.

Safe working requires a high degree of competence for all those involved from the earliest stages of planning through procurement, construction, commissioning and for maintenance and renovation. It also requires continuous monitoring and review.

This Code highlights the importance of planning in relation to health and safety risks and provides requirements for managing health and safety risks of construction given there has been significant change and technological development in the industry.

1.2 Who has health and safety duties?

There are a number of duty holders who have a role in managing the risks associated with tunnels, including those listed below.

A person can have more than one duty and more than one person can have the same duty at the same time.

The main duty holders and key legislative provisions have been referenced in the table below, however the list is not exhaustive.

1 Including the risks from groundwater

Duty holder	Application
Person conducting a business or undertaking (PCBU) WHS Act sections 19, 46 and 47 WHS Regulation section 55C	A PCBU must eliminate risks to health and safety, or if that is not reasonably practicable, minimise the risks so far as is reasonably practicable. This includes: • the provision and maintenance of a work environment without risks to health and safety, • the provision and maintenance of safe plant and structures, • the provision and maintenance of safe systems of work, • the safe use, handling, and storage of plant, structures and substances, • the provision of information, training, instruction and supervision necessary to protect people from risks to health and safety, • the provision of adequate facilities for the welfare at work of workers, • monitoring the health and conditions of the workplace to prevent illness and injury, • managing psychosocial hazards. PCBUs also have duties to: • consult workers about work health and safety, • consult, cooperate and coordinate with other duty holders, • ensure that the health and safety of other persons is not put at risk from work carried out as part of the conduct of the business or undertaking. PCBUs working in tunnelling operations will have concurrent or shared duties. All PCBUs, so far as is reasonably practicable, must consult, cooperate, and coordinate together to manage their shared duties.
PCBU with management or control of a workplace WHS Act section 20	Must ensure, so far as is reasonably practicable, that the workplace, the means of entering and exiting the workplace and anything arising from the workplace are without risks to the health and safety of any person.
Designers, manufacturers, importers, installers and suppliers of plant, substances or structures WHS Act sections 22-26	Must ensure, so far as is reasonably practicable, the plant / substances / structures they design, manufacture, import, supply or install are, so far as is reasonably practicable, without risks to health and safety including carrying out testing and analysis and providing information about the risks posed to users of the plant, substances or structures.
Persons with management or control of fixtures, fittings and plant at a workplace WHS Act section 21	Must ensure, so far as is reasonably practicable, that the fixtures, fittings and plant are without risks to the health and safety of any person.

Duty holder	Application
Officers WHS Act section 27	Officers of the PCBU must exercise due diligence to ensure the PCBU complies with the WHS Act and WHS Regulation. This includes maintaining up to date WHS knowledge and taking reasonable steps to ensure the business or undertaking has and uses appropriate resources and processes to eliminate or minimise risks to health and safety from tunnels under construction work. Further information on who is an officer and their duties is available in Safe Work Australia's *Interpretive Guideline: The health and safety duty of an officer*.
Workers WHS Act section 28 WHS Regulation section 46	While at work, workers must: • take reasonable care for their own health and safety, • take reasonable care that their actions or omissions do not adversely affect the health and safety of other persons, • comply with any reasonable instructions given by the PCBU, as far as they are reasonably able, • cooperate with any reasonable health and safety policies or procedures of the PCBU. If personal protective equipment (PPE) is provided by the PCBU, the worker must, so far as they are reasonably able, use or wear it in accordance with the information and instruction and training provided.
Other persons at the workplace WHS Act section 29	A person at a workplace must: • take reasonable care for their own health and safety, • take reasonable care that their acts or omissions do not adversely affect other people's health and safety, • comply, so far as they are reasonably able, with reasonable instructions given by the PCBU to allow the PCBU to comply with the WHS Act.

Duty holder	Application
Principal contractors on construction projects WHS Act section 20 WHS Regulation sections 293, 299, 301 and 307-315	Principal contractors are a PCBU who commissions a construction project or is engaged to be a Principal Contractor by the person who commissioned the project. Principal Contractors hold additional duties under the WHS Regulation, including that they must: • prepare a written WHS management plan for the workplace, • ensure, so far as is reasonably practicable, that each worker is made aware of the content of the WHS management plan before they start work, • review and as necessary revise the WHS management plan to ensure that it remains up to date, • establish and maintain consultation arrangements with other PCBUs, contractors, subcontractors and workers, • manage risks associated with the construction project, • ensure a Safe Work Method Statement (SWMS) is prepared for high risk construction work, • take all reasonable steps to obtain a copy of the SWMS and ensure it is followed when conducting high risk construction work, • put in place arrangements for ensuring that PCBUs and other duty holders comply with their obligations under the WHS Regulation. When engaging specialist businesses and/or workers to deliver specific works, a Principal Contractor should: • verify that mobile plant supplied is suited to the task and maintained, • ensure there are processes for the verification of worker competency in the operation of mobile plant, • ensure workers are inducted to the site requirements.
PCBUs working on construction projects e.g. subcontractors WHS Act section 19	PCBUs working on construction projects must: • work within the requirements of the WHS management plan, • develop SWMS for the high risk construction work that they control, • verify that works are being completed in accordance with the SWMS, • verify that any mobile plant used or supplied is suited to the work and maintained, • ensure workers are provided with suitable and adequate information, training and instruction in completing the required work.

1.3 Consultation

This table includes recommendations on how to comply with the WHS legislative requirements.

Duty / Provisions	Application
Consulting workers WHS Act section 47-49	• PCBUs have a duty to consult with workers, so far as reasonably practicable, on WHS matters which affect them. • Consultation is a two-way process with workers to identify WHS issues, share information, give workers a reasonable opportunity to express views and take those views into account before making decisions about health and safety matters. • While consultation may not always result in agreement, agreement should be the objective as it will make it more likely the decisions are effective and actively supported. • Workers should be encouraged to report hazards and health and safety problems immediately so the risks can be managed before an incident occurs. • If workers are represented by a health and safety representative, the consultation must involve that representative. • Workers must be advised of consultation outcomes in a timely manner. • PCBUs must have effective mechanisms to consult with workers, including when: — identifying hazards and assessing risks, — making decisions about ways to eliminate or control risks, — changing or updating workplace facilities, — proposing changes that may affect the health and safety of workers, — making decisions about consultation procedures, resolving safety issues, monitoring workers' health, working environment, and providing information and training, — selecting new equipment, — introducing new tasks, changing existing tasks or carrying out work in new environments.
Consulting, cooperating and coordinating activities with other duty holders WHS Act section 46	• PCBUs must, as far as reasonably practicable, consult, cooperate and coordinate activities with all other persons who have a WHS duty in relation to the same matter. • Duty holders should exchange information about who is doing what to ensure effective coordination of works and management of risks, this includes: — the PCBU engages workers to carry out work, — the PCBU directs or influences workers in carrying out work, — other persons may be put at risk from work carried out in their business or undertaking, — the PCBU manages or controls a workplace or the fixtures, fittings or plant at a workplace, — the PCBUs business or undertaking involves designing, manufacturing, importing or supplying plant, substances or structures for use at a workplace, — the PCBUs business or undertaking involves installing, constructing or commissioning plant or structures at a workplace.

Further guidance on consultation requirements is available in the *Code of practice: Work health and safety consultation, cooperation and coordination.*

1.4 Information, training, instruction and supervision

Duty / Provisions	Application
Information, training, instruction or supervision WHS Act section 19 WHS Regulation section 39	• PCBUs must provide any information, training, instruction, or supervision necessary to protect all persons from health and safety risks, including when using plant. • The information, training and instruction: — must be suitable and adequate for the nature of works, risks and control measures implemented, — must be readily understandable to the person it is being provided to, so far as is reasonably practicable, — should be supported by relevant safe work procedures, e.g. emergency procedures, traffic rules, PPE, — should be provided to workers by a competent person, — should be practical and 'hands on' and take into account the particular needs of workers.

2. Risk management process

2.1 Overview

Risk management is a systematic process to eliminate or minimise the potential for harm to people.

Risk management should be a continuous process that starts at the earliest stages of project concept definition, extends through planning and procurement, design, construction, operation and beyond. It requires a structured, systematic approach to identifying hazards, assessing risks, applying effective risk control measures, and maintaining and reviewing them.

It is important to consider risks that may be unlikely to occur but that have significant consequences (low probability high consequence risks).

2.2 Hierarchy of Control

The hierarchy of control measures set out in Part 3.1 of the WHS Regulation can be applied in relation to any risk.

The WHS Regulation makes it mandatory for duty holders to work through this hierarchy when managing certain risks. The sections that require the process in Part 3.1 to be followed are set out below.

WHS Regulation reference
Chapter 3 General risk and workplace management, Part 3.2 General workplace management
Division 6 Remote or isolated work, Section 48 Remote or isolated work
Division 8 Hazardous atmospheres, Section 51 Managing risks to health and safety
Division 8 Hazardous atmospheres, Section 52 Ignition sources
Division 10 Falling objects, Section 54 Management of risk of falling objects
Division 11 Psychosocial risks, Section 55C Managing psychosocial risks
Chapter 4 Hazardous work, Part 4.1 Noise
Section 57 Managing risk of hearing loss from noise
Chapter 4 Hazardous work, Part 4.2 Hazardous manual tasks
Section 60 Managing risks to health and safety
Chapter 4 Hazardous work, Part 4.3 Confined spaces
Division 3 Duties of person conducting business or undertaking, Section 66 Managing risks to health and safety
Chapter 4 Hazardous work, Part 4.4 Falls
Section 78 Management of risk of fall
Chapter 4 Hazardous work, Part 4.7 General electrical safety in workplaces and energised electrical work
Division 2 General risk management, Section 147 Risk management
Chapter 4 Hazardous work, Part 4.8 Diving work
Division 3 Managing risks-general diving work, Section 176 Management of risks to health and safety
Chapter 5 Plant and structures, Part 5.1 General duties for plant and structures
Division 7 General duties of a person conducting a business or undertaking involving the management or control of plant, Section 203 Management of risks to health and safety
Division 7 General duties of a person conducting a business or undertaking involving the management or control of plant, Section 214 Powered mobile plant — general control of risk
Chapter 6 Construction work, Part 6.3 Duties of person conducting business or undertaking
Division 1 General, Section 297 Management of risks to health and safety
Division 3 Excavation work, Section 305 Management of risks to health and safety associated with excavation work
Chapter 6 Construction work, Part 6.4 Additional duties of principal contractor
Section 315 Further health and safety duties — specific risks
Chapter 7 Hazardous chemicals, Part 7.1 Hazardous chemicals
Division 5 Control of risk-obligations of persons conducting businesses or undertakings, Section 351 Management of risks to health or safety
Division 9 Pipelines, Section 391 Management of risks to health and safety by pipeline operator
Chapter 8 Asbestos, Part 8.4 Management of naturally occurring asbestos
Section 431 Naturally occurring asbestos

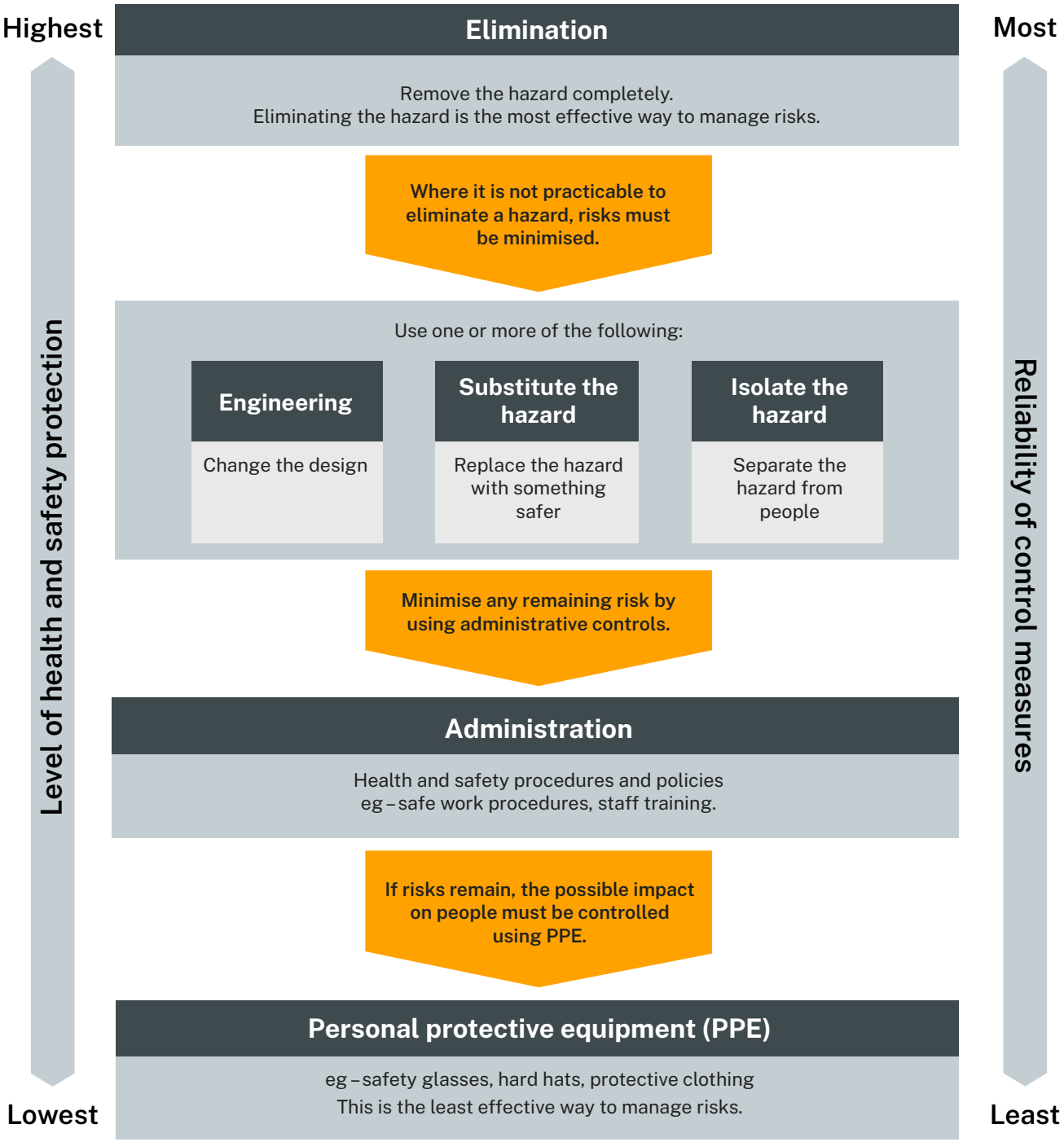

Figure 1: An overview of the Hierarchy of control measures

Further risk management guidance is available in the:

- *Code of practice: How to manage work health and safety risks*
- *Code of practice: Managing psychosocial hazards at work*
- *Code of practice: Sexual and gender-based harassment*

For the purposes of this Code a control measure is not considered effective solely because it is present or specified; it must function as intended in the circumstances in which it is used and contribute to the elimination or minimisation of risk, so far as is reasonably practicable.

The use of a control measure considered as effective does not imply that exposure is eliminated or that no residual risk remains. Where a person remains at risk after one or more control measures are implemented, additional control measures must be implemented, including, where required, administrative controls, and the provision and use of PPE, in accordance with the WHS Regulation.

Appropriate selection, correct use, maintenance, inspection, monitoring and review are required to ensure control measures are, and remain, effective.

2.3 Client Organisations

Early planning and design decisions, e.g. regarding tunnel alignment or construction methodology, play a critical role in eliminating health and safety risks, as some risks can only be eliminated or avoided at the initial stages of a project — often before a Principal Contractor is appointed. Decisions made early may lock projects into risks that can later only be minimised, not eliminated. Risks should be clearly identified during early planning and design to enable the elimination or minimisation of risks so far as is reasonably practicable.

Client Organisations have a key responsibility to procure competent Principal Contractors and to establish effective health and safety risk management through contractual arrangements. Planning and design documentation should demonstrate that safe construction or remedial work is achievable.

Effectively managing WHS risk is an essential factor that should be considered during the contracting process, e.g. tendering process. Documentation to engage contractors should include an outline of WHS risks and requirements. Factors that should be considered include:

- Planning - is an opportunity to minimise the risk to health or safety and maximise WHS outcomes. PCBUs should consider the inherent WHS risks in the work being procured, the level of WHS capacity required to be demonstrated by service providers and the duties that the service providers will be required to comply with during the term of the contract.
- Approach to market - any documents should identify novel or elevated WHS risks and include terms to ensure risks are properly addressed.
- Evaluation - documents should require each respondent to demonstrate their capacity to meet their WHS requirements specified as well as demonstrate how they will meet their WHS duties, including consideration of past WHS performance.
- Contract management - should include any special conditions to address and manage WHS risks. Special conditions can be used to monitor and manage WHS performance during the contract term and ensure the goods and/or services are delivered in line with the WHS requirement.

PCBU should ensure continuous oversight of health and safety processes which may be undertaken through formal reviews conducted throughout design, construction, and whenever changes occur. At each stage, Client Organisations should carry out health and safety reviews informed by experienced personnel or supplement their expertise where necessary. This can be supported by live risk registers that document identified issues, residual risks, and ownership responsibilities. The risk register should be a live document, updated as and when new risks are identified. Persons involved in the review should be competent in their area of expertise and named in the review documentation.

2.4 Competence

An essential aspect of effective health and safety risk management is role definition and role competence. PCBUs should clearly define roles and responsibilities.

PCBUs should establish systems of work to ensure that each person involved in the construction project is competent to carry out their role and each PCBU involved in the project should ensure that their workers are competent to carry out the work required of them.

2.5 Concurrent duties of PCBUs

Work health and safety duties exist throughout the design and planning phase, tendering and contractor selection, and the entire lifecycle of the structure or project.

PCBUs such as Client Organisations, Principal Contractors and subcontractors operating in a contracting chain will have concurrent work health and safety duties and a person can have more than one duty at the same time.

Multiple duty holders who have the same duty must each meet their duty to the standard required.

Where more than one person has a duty in relation to the same matter, the duty holders retain responsibility for their duty in relation to the matter and must discharge the duty to the extent to which the person has capacity to influence or control the matter. These duty holders must also, so far as reasonably practicable, consult, cooperate and coordinate activities with each other.

A duty holder cannot transfer their duties to another person. Any contractual term that seeks to transfer or reduce the duty holder's responsibility will be invalid.

Duty holders who have a duty in relation to the same matter can enter into reasonable arrangements or agreements with each other to make sure everyone's duties are met, while at the same time avoiding unnecessary duplication of effort.

A duty holder must manage risks to health and safety by eliminating risks, so far as is reasonably practicable, and if not reasonably practicable, to minimise those risks so far as is reasonably practicable.

3. Design

3.1 General

Health and safety considerations must inform the concept development of structures when making decisions about:

- the design and its intended purpose,
- plant and equipment to be used,
- materials to be used,
- possible methods of construction, maintenance, operation, demolition or dismantling and disposal,
- working spaces and means of access and egress,
- the legislation, codes of practice and standards that need to be complied with.

PCBUs should refer to *Code of practice: Safe design of structures* and Safe Work Australia's *Principles of good work design: A work health and safety handbook* for further information.

Health and safety in design or 'Safety in design' is a continuous process with the following principles:

- Persons with control – persons who make decisions affecting the design of products, facilities or processes can promote health and safety at the source.
- Product lifecycle – safe design applies to every stage in the lifecycle from conception through to disposal or decommissioning of assets. It involves eliminating hazards or minimising risks as early in the lifecycle as possible.
- Systematic risk management – the application of hazard identification, risk assessment and risk control processes to achieve safe design.
- Safe design knowledge and capability (competence) – should be either demonstrated or acquired by persons with control over design.
- Information transfer – effective communication and documentation of design and risk control information between all persons involved in the phases of the lifecycle is essential for the safe design approach.

At all design and construction stages, where risks cannot be eliminated by design, they must be managed by the implementation of risk controls which may be described in risk management plans.

3.2 Site investigations

The investigations should provide sufficient information to undertake assessments that inform the alignment and spatial definition of the structures to be constructed, and to assess the risks associated with design and construction.

Ground, utility and existing building and structure investigations should be in accordance with Australian Standard *AS1726:2017 – Geotechnical site investigations* or any updated equivalent and consider the type, extent and location of the tunnelling work and local environmental conditions. Investigations should be carried out by suitably qualified and experienced people competent in conducting investigations for similar purposes and in similar ground conditions. The investigations should include:

- Weather conditions: Hydrology and the potential for, and magnitude of, fluvial and pluvial flooding including the definition of any probable maximum flood level.
- Local topography: Geomorphological influences upon design and construction.

- Existing infrastructure: Accurate location, condition, evaluation and assessment of the potential influence of nearby buildings, structures, utilities and old mine workings or wells.
- Ground and groundwater characterisation: To identify soils and rocks, their variability and the potential influence on the design and construction methods, and the potential influence of groundwater including changes arising from construction and during operation. This should include assessments of risk and reliability of these assessments.
- The proportion of crystalline silica in the ground materials.
- The presence of naturally occurring asbestos (NOA).
- Potential for contaminated ground and groundwater environments, their spatial extent and concentration of contaminants: hazardous gases such as methane, industrial waste liquids and solids e.g. leachate or dumped asbestos and review of previous relevant land use and historical data for the area.

3.3 Design development for construction

When selecting Designers, Client Organisations should evaluate the competence of Designers in relation to the construction and constructability of underground structures. Designers with proven, relevant experience in underground construction should be engaged.

Client Organisations should prepare, or have prepared for them, reference designs that are sufficiently integrated and detailed to enable the planning of health and safety including defining minimum requirements and risk assessments.

PCBUs must identify foreseeable risks across the structure's entire lifecycle. These risks should be assessed in accordance with the Client Organisation's risk management criteria, applicable standards, and workplace exposure standards. Design information must specify any conditions necessary for safe construction and maintenance.

The selection of shaft and portal locations, tunnel diameter, alignment and tunnelling methods all have significant implications for health and safety risk management. Health and safety risks associated with alternative design options and alternative construction methodologies should be compared and recorded.

When planning tunnel construction and procurement, a process for developing the detailed design, suitable for construction, should be selected. Whilst there are some variations, this is most commonly either:

- design-bid-build, where the Client Organisation retains the responsibility for the detailed design, or
- design and build, where detailed design responsibility is transferred to the Principal Contractor from a reference design.

Note: Early Contractor Involvement (ECI) is a collaborative construction procurement method that may be used. ECI is where a contractor joins a project team during the early design and planning stages, rather than after the design is complete, to provide buildability, cost, and scheduling input, leading to better risk management, value engineering, and faster project delivery through a strong partnership. ECI shifts away from traditional design-bid-build by integrating the builder's practical expertise before major spending, optimising designs for efficiency and innovation while managing uncertainty.

The basis for the design must include any assumptions and assessments related to:

- the expected range of geotechnical, hydrogeological and hydrological conditions and associated risks,
- the construction methodologies and processes expected to be used, taking into account any constraints imposed by the design across all relevant design disciplines,
- any interfacing or schedule constraints requiring underground construction activities to be performed in parallel,

- accommodating future adjacent construction,
- temporary ventilation during the construction of underground working areas,
- electrical systems and supplies,
- access requirements for operation and maintenance stages,
- incident and emergency plans for fire and other emergency scenarios in consultation with local emergency services,
- PPE assessments.

With respect to ventilation system design, the Client Organisation should be satisfied that:

- reference design documents clearly incorporate minimum requirements for the design and specifications of any temporary ventilation system,
- contractor submissions meet these specifications or demonstrate how the requirements can be achieved through any alternative approaches proposed.

When tendering, Principal Contractors should assess the designs in relation to health and safety risks to establish their view of the suitability and adequacy of designs for construction from a health and safety risk management perspective. If valid potential risk reduction measures are identified by the contractors in a procurement process these should be acknowledged by Client Organisations. Similarly, Client Organisations should be vigilant with respect to innovations or changes that increase safety risks.

Prior to the appointment of a Principal Contractor, Client Organisations should assess the requirements for health and safety risk management and request a construction phase plan and associated risk management documentation that addresses the risks identified by the Client Organisation and any others identified through consultation.

3.4 Independent design verification

The main purpose of independent design verification should be to confirm that the design satisfies the design requirements and is safe to construct and be undertaken by competent persons.

Independent design verification requirements for temporary and permanent works should be established based on risk levels. Design verifications on works should be proportional to the risk of failure of those works and reflect the risk inherent in their execution.

If a design is amended after verification, the risks and materiality of the change and/or the cumulative effect of multiple design changes should be reconsidered based on risk levels. The verifier should be advised accordingly and should document their acceptance of amendments to the design.

The design verification of all ground support and lining works should take account of the constructability of the works and any associated temporary works and the changes that may arise during construction.

3.5 Updating design assumptions

During construction, the assumptions regarding ground conditions and behaviour should be confirmed (validated) and as necessary updated. The process of validation should incorporate new geological and geophysical investigations, geological logging and mapping, and monitoring data.

Validation of design assumptions is necessary to enable continuous assessment of the potential for ground risks to impact safety, including the risk of ground instability and loss of excavation control and to inform the Permit to Tunnel process (see Chapter 10.4 in this Code).

4. Quality assurance in health and safety

4.1 Overview

Quality assurance (QA) is an effective component of a health and safety management system in tunnelling projects. It ensures that all processes, procedures and practices are consistently implemented and applied and meet the required standards throughout the lifecycle of the project.

Key QA measures should include:

- Documented health and safety processes: Including risk assessments, safe work method statements (SWMS preparation, establishment and compliance monitoring), inspection and testing plans (ITPs), and emergency response procedures.
- Competency Verification: All workers involved in tunnelling activities should be verified as competent through qualifications, training, and experience with respect to their role within a project. This should include Designers, managers, engineers, supervisors, plant operators, safety officers, Ventilation Officers, and Occupational Hygienists.
- Inspection and Testing: Regular inspections and testing of plant, equipment, ground support systems and componentry, and ventilation must be conducted in accordance with approved plans. Results should be recorded, reviewed and, where required, corrective actions taken.
- Workplace and facility inspections.
- Audit and review: In consultation with the relevant PCBUs, internal and external audits should be scheduled to assess compliance with legal obligations under the WHS Act and WHS Regulation, codes of practice, and to ensure the effectiveness of control measures for project-specific safety plans such as the WHS Management Plan, Ventilation Control Plan and the Occupational Hygiene Plan.
- Continuous Improvement: Non-conformances should be documented, investigated, and used to inform corrective actions and system improvements.

4.2 Change management

Management of change is a key risk factor in underground construction.

Where the need to modify design assumptions, construction methods, equipment or work processes is identified PCBUs should manage these changes through a formal change management process to ensure that new or altered health and safety risks are identified and controlled.

Change management processes should include:

- Formal change evaluation: Proposed changes should be assessed for their potential impact on health and safety, including changes to tunnel alignment, excavation methods, support systems or ventilation design.
- Consultation and communication mechanisms: Changes must also be communicated to affected parties, including workers, contractors and designers, and consultation should be documented.
- Risk re-assessment: Changes must trigger a review of relevant risk assessments and SWMS. New hazards can be identified and control measures updated as required.
- Approval and documentation: Changes should be formally approved by a competent person or authority and documented in the project's WHS management system.
- Training and induction: Where changes affect work practices or introduce new risks, affected workers must receive appropriate training or induction before the change is implemented.

5. Health and welfare

5.1 Overview

In Australia, as in many other countries, the impacts from occupational illness are significantly greater than those from workplace accidents. Chronic conditions like hearing loss, respiratory diseases[2], and musculoskeletal disorders develop over time and often go unnoticed until they become debilitating.

PCBUs must eliminate or minimise risks so far as reasonably practicable. PCBUs should implement systematic approaches that facilitate the interpretation of relevant data and avoid underreporting and underdiagnosis of occupational illnesses and diseases.

The interpretation of data may require the involvement of relevant competent persons such as Occupational Hygienists and ventilation engineers during the planning, design and construction stages.

The outcomes of the data interpretation may assist:

- to establish performance criteria and project specific requirements,
- to assist in the development and implementation of health risk assessments, exposure control plans, and exposure monitoring programmes, and
- development of an occupational health and hygiene plan (refer Chapter 5.13).

It is noted that occupational health issues for tunnelling workers may be exacerbated as they are often required to live away from home for extended periods and this increases the potential impact of psychosocial hazards (refer Chapter 5.6).

5.2 Dust and other airborne contaminants

PCBUs must ensure that no person at the workplace is exposed to an airborne substance or mixture which exceeds the exposure standard for that contaminant. Exposure to dust is a significant health hazard during construction of underground infrastructure with debilitating and potentially fatal consequences.

PCBUs must ensure air monitoring is carried out to determine the airborne concentration of a substance or mixture at the workplace when the PCBU is uncertain of the exposure level or where the monitoring is required to determine whether there is a risk to health.

Control of exposures using the hierarchy of controls must be undertaken and should be a health and safety priority. Refer Chapters 16-19 and Appendix C, D and H.

For further information refer to Safe Work Australia's Guidance – *Interpretation of Workplace exposure standards for airborne contaminants.*

2 For example, silicosis is an irreversible lung disease that reduces the lungs' ability to take in oxygen and can be fatal.

5.3 Noise and hearing loss

Noise-induced hearing loss is a widespread issue in the construction industry. It is one of the most common and costly occupational injuries — but it is also preventable.

PCBUs must manage the risk of workplace hearing loss due to noise in line with the hierarchy of controls. This involves identifying activities which generate noise hazards and implementing control measures.

Noise exposure must be eliminated so far as reasonably practicable, or if that is not reasonably practicable, minimised as far as is reasonably practicable using the hierarchy of controls. Control measures for noise may include:

- selecting plant and equipment with lower-noise outputs,
- use of variable speed drives to reduce noise outputs if appropriate,
- fitting sound-absorbing material (e.g. workshop walls),
- initiating blasts from a distance (e.g. from the surface),
- constructing sound-deadening structures around static plant,
- fitting sound-attenuating silencers to fans, and fresh air intakes,
- fitting and maintaining mufflers to exhausts,
- applying sound-proofing material to walls and around equipment,
- increasing efficiency of silencers,
- fitting additional mufflers to exhausts,
- limiting exposure times,
- providing, maintaining and monitoring PPE.

A PCBU who directs workers in tunnelling environments to wear hearing protection (PPE) while carrying out work must ensure the PPE is selected to minimise the risk to health and safety by ensuring it is:

- suitable, having regard to the nature of work and the noise levels generated, and
- suitable to eliminate or minimise the risk posed by excessive noise exposure.

A worker who is provided with PPE by a PCBU must ensure they wear the PPE as instructed in line with the information and training provided. The worker must not intentionally misuse or damage the PPE provided and must report damage or a defect when aware.

A PCBU who provides the PPE as a control measure must provide audiometric testing for the worker. Testing must be provided:

- within 3 months of the worker commencing the work, and
- at least every 2 years.

PPE may form an essential part of the overall noise control program and, if required to be worn, must be worn consistently to be effective to reduce the risk of noise-induced hearing loss. Further information on the selection, use and maintenance of hearing protection is provided in Chapter 23.7 of this Code.

PCBUs should refer to *Code of practice: Managing noise and preventing hearing loss at work* for further information.

5.4 Hazardous manual tasks - vibration exposure

Prolonged exposure to vibration can cause temporary or permanent injury to muscles, joints, blood vessels and nerves, resulting in pain or disability. Exposure to vibration is a significant hazard in tunnelling work. Common types of vibration include hand-arm vibration (HAV) and whole-body vibration (WBV). Prolonged exposure to HAV and WBV can cause various health effects, such as hand-arm vibration syndrome, carpal tunnel syndrome, and musculoskeletal disorders affecting muscles, joints, blood vessels and nerves. Both forms of vibration can also contribute to fatigue and increase the risk of injury.

Section 60 of the WHS Regulation requires PCBUs to manage risks of musculoskeletal disorders from hazardous manual tasks, including vibration in accordance with Part 3.1 of the WHS Regulation.

When determining controls, the PCBU must consider factors that can increase the risk of harm, such as musculoskeletal disorders. These factors include posture, vibration, frequency and duration of exposure, environmental conditions, and workplace design and layout.

HAV may result from the use of handheld power tools such as grinders, hammer drills, and pneumatic tools. WBV may occur when operating vehicles or plant over uneven surfaces or when standing on vibrating platforms.

HAV can be measured on tools or work pieces in contact with the operator's hand, while WBV can be measured at the point where vibration enters the body (e.g. operator's seat).

A competent person should carry out measurements in accordance with recognised standards:

- Australian Standard *AS ISO 5349.1-2013 — Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration*
- Australian Standard *AS 2670.1:2001 — Evaluation of human exposure to whole-body vibration — Part 1: General requirements*
- European Standard *EN 14253:2003 — Mechanical vibration — Measurement and calculation of occupational exposure to whole-body vibration with reference to health — Practical guidance*.

Manufacturer data can also assist in estimating exposure. Risk may be assessed against the EU Physical Agents Directive (2002/44/EC), which sets daily exposure action and limit values.

Examples of control measures include:

- Substitution and task design: Automate tasks, improve road surfaces, reduce travel distances, or use conveyors instead of mobile plant.
- Equipment selection and design: Use fit-for-purpose tools, low-vibration equipment, antivibration handles, suspension seats, and ergonomic cabin layouts.
- Purchasing policies: Prioritise low-vibration tools and plant, factoring in emissions, ergonomics, and operational needs.
- Maintenance: Regularly service and maintain tools, plant, vehicles, and roadways.
- Work organisation: Implement work/rest cycles, rotate tasks, and provide warm clothing in cold environments.
- Training and information: Provide training in understanding vibration risks and safe practices.
- PPE: Anti-vibration gloves may help with high-frequency tools, though their benefit is limited.

PCBUs should refer to *Code of practice: Hazardous Manual Tasks*, and Safe Work Australia's *Principles of good work design: A work health and safety handbook, Guide to measuring and assessing workplace exposure to whole-body vibration, Guide to measuring and assessing workplace exposure to hand-arm vibration* and *Guide to managing risks of exposure to hand-arm vibration in workplaces* for further information.

5.5 Heat-related illness

'Heat-related illness' is a term that describes a range of progressive heat-related conditions and occurs when circumstances including a worker's environment, work activity, clothing and PPE interact to produce core body temperature rises.

Factors and sources of risk that may lead to a heat-related illness risk must be identified by PCBUs and the associated risk must be eliminated, or if that is not reasonably practicable, minimised through the application of the hierarchy of control measures. Control measures for minimising heat-related illness may include:

- providing adequate ventilation,
- reducing items of heat-producing equipment underground,
- relocating hot processes away from high-access or enclosed areas,
- installing barriers to absorb or deflect radiant heat, e.g. reflective barriers,
- using mechanical aids to reduce metabolic workload for heavy or moderate activities,
- limiting exposure times,
- fitting enclosed mobile plant with air conditioning,
- delivering heat stress awareness training,
- reducing work intensity during high thermal risk periods,
- providing heat acclimatisation programs,
- supplying cool drinking water (including ice machines),
- providing access to air-conditioned rest areas,
- encouraging self-paced work and reporting of heat stress symptoms,
- verifying plant air-conditioning is operational and maintained.

Researchers have developed an index for Thermal Work Limits (TWL) (Miller & Bates, 2007) for an equivalent metabolic rate that hydrated, acclimatised individuals can maintain within a specific thermal environment, for a safe deep body core temperature (<38.2oC) and sweat rate (<1.2 kg/hr). This has led to the development of the following recommendations, limits and interventions as reported by the Australian Institute of Occupational Hygienists – AIOH. PCBUs should give consideration to this information when establishing what is reasonably practicable.

Table 1: Thermal Work Limit (TWL) Risk Categories and Controls

Risk Level	TWL (W/m^2)[3]	Comments and controls
Low	>220	– Unrestricted self-paced work – Ensure adequate fluid replacement
Moderate Low	181–220	– Acclimatisation Zone – Self-paced work possible for well-hydrated, acclimatised workers – No unacclimatised worker to work alone – Ensure adequate fluid replacement
Moderate High	141–180	– Acclimatisation Zone – No worker to work alone – Ensure adequate fluid replacement
High	116–140	– Buffer Zone – Workload exceeds TWL; heat storage limits work time – No unacclimatised worker to work – No worker to work alone – Increase airflow >0.5 m/s – Redeploy workers where practicable – Ensure adequate fluid replacement – Hydration testing; withdraw if dehydrated – Apply work/rest cycling – Work only with authorisation and management controls
Critical	<116	– Withdrawal Zone – Essential maintenance to fix or implement additional controls to improve conditions and rescue work only – No worker to work alone – No unacclimatised worker to work – Ensure adequate fluid replacement – Apply work/rest cycling – Consider physiological monitoring

Note: Unacclimatised workers are defined as new workers or those who have been off work for more than 14 days due to illness or leave (outside the tropics).

For more information, and recommendations for managing heat stress refer to Safe Work Australia's *Guidance material: Managing the risks of working in heat* and *NSW Resources Regulator's Legislative obligation: health control plans – NSW mining and extractives industry* Fact Sheet PUB18-36.

3 Watts per metre squared

5.6 Psychosocial hazards

WHS Regulation sections 55A – 55D

Psychosocial risks

Workers can be exposed to a combination of work-related psychosocial hazards and risks factors. A PCBU has a duty to manage the risk of psychosocial hazards in the workplace. A PCBU must eliminate psychosocial risks, or if that is not reasonably practicable, minimise them so far as is reasonably practicable in accordance with the hierarchy of controls.

In determining the control measures to implement to manage the psychosocial hazard, PCBUs must have regard to all relevant matters including:

- duration, frequency and severity of exposure of workers and other persons,
- how the psychosocial hazards may combine or interact,
- design of work, including job demands and tasks,
- system of work, including how work is managed, organised and supported,
- design, layout and environmental conditions of workplace, including safe means of entering and exiting the workplace and facilities for the welfare of workers,
- the design and layout, and environmental conditions, of workers accommodation,
- plant, substances and structures at the workplace,
- workplace interactions or behaviours,
- information, training, instruction and supervision given to workers.

Some examples of psychosocial hazards may include:

- role overload (high workloads or job demands), e.g. high levels of physical, mental or emotional effort are needed to do the job,
- hazardous physical working environments, e.g. performing hazardous work, conditions that affect concentration or cause discomfort,
- remote or isolated work (e.g. working extended periods alone),
- working in camps (PCBUs should refer to *Code of practice: Worker accommodation* for further information).

PCBUs should refer to the *Code of practice: Managing psychosocial hazards at work* for further information.

5.7 Fatigue

Physical or mental fatigue can reduce a worker's ability to perform tasks safely, increasing the risk of injury or incident. According to the *Code of practice: Managing the risk of fatigue at work*, "Fatigue is a state of physical, mental or emotional impairment. Fatigue can develop over the short or long term, can prevent people from functioning safely and can have health effects".

Fatigue may result from prolonged working including shift work, heavy workload, insufficient rest and inadequate sleep. This can result in impairment from being less able to process information, slower reaction times, and greater vulnerability to human error.

PCBUs must manage fatigue risks as part of their WHS duties by following the risk management process:

- Identify hazards – consider work demands, environment, scheduling, shift length, shift rosters and non-work factors.
- Assess risks – evaluate likelihood and severity, including cumulative fatigue.
- Control risks – apply the hierarchy of control (eliminate, substitute, engineering, administrative, PPE).
- Review controls – monitor effectiveness and adjust as needed.

PCBUs should follow up when a worker identifies difficulties they may have and encourage workers to seek medical advice to manage both temporary illnesses and chronic health conditions which may cause fatigue.

Control measures may include:

- Work Design: Plan rosters to allow adequate rest and recovery; consider shift length, patterns, travel time, and handover requirements;
- Accommodation: provide accommodation conducive to sleep for remote workers.
- Worker Responsibilities: Ensure fitness for work and self-identify when unfit; cooperate with fatigue management measures.
- Health Support: Encourage workers to seek medical advice for temporary illnesses or chronic conditions contributing to fatigue.
- Psychosocial Hazards: Recognize fatigue as a psychosocial hazard under the WHS Regulation.

PCBUs should consult with workers and their HSRs when identifying risks and implementing controls and provide workers with information, training and instruction on fatigue risks, symptoms and safe practices.

If PCBUs provide accommodation they should ensure workers' temporary residential accommodation arrangements are conducive to sleep when workers need to work away from home.

PCBUs should refer to *Code of practice: Managing the risk of fatigue at work* and *Code of practice: Worker accommodation* for further information. (Refer also Chapter 5.6 Psychosocial hazards in this Code).

5.8 Skin health

Underground construction workers are at increased risk of developing occupational skin conditions, particularly occupational contact dermatitis, due to exposure to irritants, allergens, wet work, and prolonged use of occlusive PPE. Common contributors include contact with wet concrete, cementitious grout, bentonite, oils and greases, solvents, cleaning agents, dusts, and contaminated water. A Safety Data Sheet (SDS) is an important tool for assessing and managing the risks associated with the use of hazardous chemicals in workplaces.

PCBUs should refer to the *Code of practice: Managing risks of hazardous chemicals in the workplace* for further information.

PCBUs must identify skin health hazards and eliminate or minimise risks so far as is reasonably practicable through the application of the hierarchy of controls. This may be done as part of an occupational health risk assessment process.

Control measures may include:

- Substitution and product selection:
  - use less irritating or sensitising substances and cleaning products where practicable.
- Engineering and environmental controls:
  - mechanisation or enclosure of processes involving wet or corrosive materials,
  - provision of adequate washing facilities located close to work areas,
  - effective ventilation to reduce humidity and skin maceration.
- Administrative controls:
  - limiting duration of wet work and glove use,
  - task rotation to reduce prolonged exposure,
  - procedures prohibiting the use of solvents, fuels, or abrasive materials for skin cleaning,
  - early reporting and intervention processes for skin irritation.
- Personal Protective Equipment (PPE):
  - selection of task-appropriate gloves (e.g. nitrile, PVC),
  - correct glove sizing and change-out practices,
  - use of protective clothing where required,
  - avoidance of prolonged occlusive glove use without breaks.

A structured skin care regime should be implemented for all workers and incorporated into the site's work health management plan or system. The regime should include:

- provision of suitable pre-work barrier creams where appropriate,
- pH-neutral, non-abrasive hand cleansers,
- moisturising creams for use after handwashing and at the end of shifts,
- ready availability of skin care products at point of use.

Adequate welfare facilities must be provided in accordance with Chapter 5.10, including access to warm water, handwashing facilities, drying amenities, and showering facilities to support effective skin hygiene.

Workers must receive information, instruction, and training on:

- skin health risks associated with tunnelling work,
- correct use and limitations of PPE,
- early signs and symptoms of occupational dermatitis,
- reporting procedures and available support.

PCBUs should consider skin health risks as part of the site's health monitoring program (refer Chapter 5.12). Where exposure to hazardous substances presents a significant risk, PCBUs should ensure early identification, referral, and medical management of skin conditions to prevent progression to chronic disease.

For workers undertaking surface activities associated with tunnel construction, risks from ultraviolet (UV) radiation must be assessed and controlled by PCBUs. Controls may include provision of sun-protective clothing, sunscreen, shaded rest areas, and work scheduling to minimise exposure.

For further information refer to Safe Work Australia's *Guide on exposure to solar ultraviolet radiation (UVR).*

5.9 Hazardous chemicals

Tunnelling work can involve exposure to a wide range of hazardous chemicals that are either introduced into the workplace or generated during construction activities. These substances can cause serious harm if that exposure is not eliminated or not effectively controlled. Examples include:

- gases such as ammonia and hydrogen sulphide which may be released from old sewer pipes, and groundwater encountered during excavation, or gases produced from explosives while blasting,
- chemical burns – from substances such as wet concrete and cementitious grout,
- exposure to hexavalent chromium when working with concrete and shotcrete,
- exposure to isocyanates from waterproofing products,
- exposure to volatile organic compounds (VOCs) from waterproofing, concrete curing agents, and paints,
- exposure to hazardous chemicals that are generated as part of work activities such as RCS, diesel exhaust and welding fumes and gases.

PCBUs should refer to the *Code of practice: Managing risks of hazardous chemicals in the workplace* for further information.

5.10 Welfare facilities

Welfare provisions on site must include, so far as reasonably practicable, drinking water, toilets, washing facilities and eating facilities readily accessible to all workers (including underground workers). Clothes storage, laundry, and drying facilities should also be provided.

PCBUs should refer to *Code of practice: Managing the work environment and facilities* for further information.

5.11 Biological hazards

Biological hazards such as mould and legionella can be present in tunnelling work environments.

Mould can develop in tunnels and underground structures or plant where organic material is present and has been stored in damp or wet conditions and ventilation is insufficient. Sources of moisture include groundwater ingress, water used in dust suppression, and condensation on surfaces. Poor ventilation prevents effective drying and increases humidity, creating conditions favourable to mould growth. To prevent mould, water ingress should be controlled, ventilation maintained to reduce humidity, and contaminated materials promptly removed or cleaned. Periodic inspection of the tunnel environment to identify mould or conditions favourable to mould growth (food source, cardboard, timber etc) should be undertaken.

Legionella bacteria can grow in water systems where water is stagnant, stored, or recirculated, particularly in the temperature range of 20°C to 45°C. Poorly maintained systems increase the likelihood of Legionella proliferation, which can cause Legionnaires' disease if contaminated aerosols are inhaled. Water systems should be designed, operated, and maintained to minimise stagnation and biofilm build-up, with regular cleaning, disinfection, and monitoring carried out in accordance with recognised standards.

5.12 Health monitoring

PCBUs must ensure health monitoring is provided to a worker carrying out work for the business or undertaking if:

- the worker is carrying out ongoing work using, handling, generating or storing hazardous chemicals and there is a significant risk to the worker's health because of exposure to a hazardous chemical referred to in Schedule 14, Table 14.1 of the WHS Regulation, or
- the PCBU identifies that because of ongoing work carried out by a worker using, handling, generating or storing hazardous chemicals there is a significant risk that the worker will be exposed to a hazardous chemical (other than a hazardous chemical referred to in Schedule 14, Table 14.1 of the WHS Regulation) and either:
  - valid techniques are available to detect the effect on the worker's health, or
  - a valid way of determining biological exposure to the hazardous chemical is available and it is uncertain, on reasonable grounds, whether the exposure to the hazardous chemical has resulted in the biological exposure standard being exceeded.

Health monitoring of a worker means monitoring the worker to identify changes in their health status because of exposure to certain substances. Health monitoring, which may include biological monitoring, takes into account all routes of exposure and not just exposure by inhalation of airborne contaminants. It 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.

Health monitoring allows decisions to be made about implementing ways to eliminate or minimise the worker's risk of exposure, for example reassigning a worker to other duties that involve less exposure or improving control measures.

Schedule 14, Table 14.1 of the WHS Regulation includes the type of health monitoring that must be carried out for each hazardous chemical listed, unless:

- an equal or better type of health monitoring is available, and
- the use of that other type of monitoring is recommended by a registered medical practitioner with experience in health monitoring.

Health monitoring is not an alternative to implementing control measures. Health monitoring is a way of identifying if control measures are effective. If the results of health monitoring indicate that a worker is experiencing adverse health effects or signs of exposure to a hazardous chemical, the control measures must be reviewed and, if necessary, revised.

The PCBU must:

- inform workers and prospective workers about health monitoring requirements,
- ensure health monitoring is carried out by or under the supervision of a registered medical practitioner with experience in health monitoring,
- consult workers in relation to the selection of the registered medical practitioner,
- pay all expenses relating to health monitoring,
- provide certain information about a worker to the registered medical practitioner,
- take all reasonable steps to obtain a report from the registered medical practitioner as soon as practicable after the monitoring has been carried out,
- provide a copy of the report to the worker as soon as practicable after obtaining the report,

- provide a copy of the report to SafeWork NSW if the report contains test results that indicate the worker may have contracted a disease, injury or illness or recommends remedial measures should be taken as a result of the work that triggered the requirement for health monitoring,
- provide the report to all other PCBUs who have a duty to provide health monitoring for the worker as soon as reasonably practicable after obtaining the report,
- keep reports as confidential records for at least 30 years after the record is made (40 years for reports relating to asbestos exposure), and
- not disclose the report to anyone without the worker's written consent unless required under the WHS Regulation.

The WHS Regulation also contains specific requirements relating to health monitoring for lead (refer Part 7.2 of the WHS Regulation), asbestos (refer Part 8.5 of the WHS Regulation) and crystalline silica (refer Part 8A of the WHS Regulation). Further information on health monitoring can be found in SafeWork NSW website: *Health monitoring* and the *Code of practice Managing risks of respirable crystalline silica in the workplace*.

Specific requirements regarding health monitoring for Respirable Crystalline Silica are provided in Chapter 19 in this Code.

5.13 Development of an occupational health and hygiene plan

Due to the complexity of hazard and risk interaction in tunnelling work, all tunnel projects should develop an occupational health and hygiene plan to provide a structured combination of controls to manage and minimise risk. The plan should, as a minimum, include the following:

(a) accountabilities, responsibilities and relevant authority, including nomination of the Occupational Hygienist,

(b) the development of procedures for the control of occupational health hazards, the use, maintenance and inspection of those procedures and control measures and validation of their effectiveness,

(c) the competencies of those who undertake exposure/air monitoring of occupational health hazards,

(d) the processes that will ensure that only those with the required competencies perform the identified tasks,

(e) the processes for assessment and evaluation of health risks, including the identification of workers, or groups of workers, to participate in exposure/air monitoring, noise and vibration monitoring, respirator fit testing, medical assessment and health monitoring activities,

(f) identification of similar exposure groups,

(g) criteria for exposure acceptability, including relevant workplace exposure limits and trigger action response plans (TARP) for exposure monitoring and real-time monitoring,

(h) criteria for equipment and instrumentation inspection, maintenance, testing and calibration,

(i) the processes to assess and verify the adequacy of control measures implemented to eliminate or otherwise reduce exposure,

(j) the standardised methods for the assessment of occupational health hazards such as dusts, noise, heat, cold and other hazards,

(k) the minimum frequency of exposure/air monitoring,

(l) the processes to re-sample following any exposure/air monitoring result that was deemed to be 'invalid' as per the standardised method selected,

(m) the methods to determine compliance with the workplace exposure standards,

(n) training needs, including hazard-specific training, accredited or approved crystalline silica training,

(o) the reporting procedures relating to exposure/air monitoring, including methods to communicate the results to workers, their representatives, and the workforce,

(p) the procedures to be followed in the event of an exceedance of an exposure standard and/or the failure of control measures implemented to eliminate or minimise risks to health, including relevant notifications,

(q) the reporting procedures relating to health monitoring, including methods to communicate the results to workers,

(r) the procedures to be followed in the event of an adverse result from health monitoring, including relevant notifications.

6. Communications, signs and signals

6.1 Communications

To minimise risks to the health and safety of workers underground a PCBU must provide and maintain a system of work that enables effective communication with and between workers.

Effective communication between workers above and below ground is essential. Surface personnel should be able to identify the location of underground workers and maintain contact, particularly to enable a timely response in the event of an incident or emergency.

A reliable and effective communication system must be provided between surface and underground work areas whenever workers are present underground. The system must be:

- maintained in a serviceable condition, and
- tested at regular intervals to verify functionality.

The communication system should be used to link:

- remote or isolated workers,
- major workplaces,
- tunnel portal and faces,
- top and bottom of shafts,
- restricted spaces, like smoke ducts and conduit passages,
- site offices,
- safety critical locations like first aid and emergency control rooms,
- mobile plant including personnel transport vehicles.

When electronic communication systems, including telemetry, are used, they should be continuously monitored at the receiving point (such as in a control room) by workers who are trained in the site's emergency plan.

When selecting a communication system, consideration should be given to:

- the size, length, and layout of the tunnel,
- the number of workers underground,
- the tunnelling method and work processes, including material supply and muck handling, and
- potential hazards, including the speed and interaction of operations.

Details of any audible or visual signal codes, call signs, channel allocations, emergency response requirements, and system operation information must be provided to workers and practised as required by their role. The provision of information, training and instruction to workers must be suitable and adequate having regard to:

(a) the nature of the work carried out by the worker, and

(b) the nature of the risks associated with the work at the time the information, training or instruction is given, and

(c) the control measures implemented.

The information, training and instruction must be given in a way that is readily understandable by a person to whom it is given e.g. through task-specific inductions and SWMS.

The communication system should be capable of operating independently of the tunnel power supply, including provision of an uninterruptible power supply. The system should be designed so that the failure of one component does not disable other parts of the system.

Communication cables and wiring, particularly those used for emergency warnings, must be protected e.g. against fire, water ingress, and mechanical damage.

An effective emergency warning system should be provided and capable of being activated quickly to alert workers underground to evacuate. Emergency warning systems must be inspected, tested and maintained to ensure effectiveness, e.g. through emergency evacuation drills, and communication protocols should be documented in the Emergency Management Plan (refer Chapter 21 of this Code).

Communication systems should be installed in shafts to coordinate transport and respond to emergencies.

6.2 Information, training, instruction and supervision

A PCBU must provide, so far as is reasonably practicable, any information, training, instruction or supervision necessary to protect all persons from risks to their health and safety arising from work carried out.

A PCBU must ensure that information, training and instruction provided to a worker is suitable and adequate having regard to:

- the nature of the work carried out by the worker,
- the nature of the risks associated with the work at the time the information, training or instruction is provided,
- the control measures implemented.

A PCBU must ensure, so far as is reasonably practicable, the information, training and instruction is provided in a way that is readily understandable by any person to whom it is provided. Training should be provided to workers by a competent person. PCBUs should also provide induction and refresher training.

Induction training should:

- inform workers of site-specific hazards, risks and control measures,
- familiarise workers with the WHS Management Plan, SWMS, tunnelling under construction operations and other WHS procedures,
- include the following:
  - site-specific tunnelling hazards and controls,
  - tunnel ventilation,
  - occupational hygiene,
  - emergency procedures and self rescue,
  - safe operating and work procedures,
  - communication systems,
  - first aid and amenities,
  - fatigue management,
  - hazard and incident reporting,

- record keeping,
- consultation arrangements and issue resolution processes.

Refresher training should:

- ensure key WHS requirements are understood, competencies are verified and maintained in view of current best practices,
- monitor work techniques and practices to maintain standards.

Effective supervision:

- is essential for maintaining a safe and healthy working environment,
- the level and type of supervision required depends on the:
  - skills and competence of the worker,
  - risk levels and risk controls to be applied including monitoring systems and communications,
  - precedence and novelty of the methods to be used,
  - working conditions.
- requires systematic oversight and experienced personnel.

6.3 Safety signage

Safety signs provide warning of hazards and risks, and may indicate safe travel routes, and provide emergency information. Safety signs must be used where administrative controls are required in addition to higher level controls such as isolation, substitution and engineering control measures. Signage should comply with Australian Standard *AS 1319:1994 – Safety Signs for the occupational environment*.

7. Safe access and egress

7.1 General

Safe access and egress must be provided for and maintained for all workers at all times including emergency scenarios (refer Chapter 21). This should include:

- clearly marked and unobstructed routes,
- protection from mobile plant and equipment,
- controlled access to underground areas,
- prohibited areas securely covered or barricaded with appropriate signage.

Tunnel portals, shafts and inclines used for access or ventilation must be designed, constructed and maintained to prevent collapse, control water ingress, restrict unauthorised access and prevent falls or entrapment.

Where reasonably practicable, PCBUs should provide at least two independent and reliable means of access and egress, such as fixed ladders, stairways, or hoisting systems, that are equipped with effective communication systems and emergency lighting.

7.2 Transport systems and walkways for workers

Worker transport systems should be designed to prevent collision or entrapment, include emergency stop mechanisms, and be operated only by trained workers.

Workers and materials should be transported separately unless specifically designed systems are in place to ensure safety.

Walkways within tunnels and shafts must be clearly delineated, slip-resistant, and free from obstructions. They must be adequately illuminated and ventilated and include handrails or barriers where there is a risk of falling. Where walkways are used for emergency egress, they must be clearly identified and lead to a safe exit point.

7.3 Tunnel entry procedures

A tunnel entry control procedure should be established and effectively implemented when workers are underground to prohibit unauthorised access underground and to ensure accurate accounting of workers underground at all times during construction, operation, maintenance, or should an emergency occur (refer Chapter 21).

Control measures such as lighting, drainage, and ventilation systems must be operational, and project induction requirements should be completed before entry is permitted.

The induction process should ensure that workers are competent for the tasks they are required to undertake. As part of entry procedures, personnel, including visitors, should confirm they understand the project health and safety provisions affecting them. Such requirements may include:

- accessibility limitations and prohibitions,
- prohibited items,
- correct use of PPE,
- emergency response procedures.

8. Temporary works

8.1 Overview

Temporary works are an essential element of safety risk management during tunnel construction and are described in some detail in this Code of practice accordingly.

The scope and procedural requirements for verification checks for temporary works designs and the process for managing design changes should be established to ensure risks are eliminated or minimised so far as reasonably practicable. These should be established as part of the quality assurance process, prior to construction and be proportionate to the risks of failure (refer Chapters 3 and 4).

SWMS must be developed and available for all high risk construction work including temporary works. PCBUs should refer to *Code of practice: Construction Work* for further information.

8.2 Principal Contractor

The Principal Contractor should ensure the appointment of competent persons to ensure safety in the design, checking, construction/installation use and de-commissioning of temporary works, and must ensure consultation, cooperation and coordination occurs between PCBUs e.g. contractors and sub-contractors.

8.3 Examples of temporary works

Examples of temporary works associated with tunnelling include:

- Access and egress systems: e.g. scaffolding, ladders, stairways, walkways, safe entry and exit points for workers, shafts and portals, and inundation protection systems (refer Chapters 7 and 9).
- Shafts, walls and propping (refer Chapter 9).
- Temporary tunnel linings and ground support (refer Chapter 10).
- Tunnel boring machines (TBMs), or pipejacking machine jacking frames and spoil management systems (refer Chapter 10).
- Shuttering/formwork and falsework (refer Chapter 10).
- Dewatering systems to remove water from the excavation area and prevent flooding from groundwater (refer Chapter 11).
- Compressed air, water supply and power utilities.
- Haulage and transportation systems such as conveyor belts, rail systems, multi-service vehicles (MSVs) and cranes to move materials in and out of the tunnel (refer Chapter 12.10).
- Gantry crane and all mobile crane foundations or supporting ground (refer Chapters 12 and 15).
- Ventilation systems to control the air quality and temperature inside the tunnel (refer Chapters 16 and 17).

9. Shafts and portals

9.1 Overview

Tunnelling or pipejacking inevitably require construction of shafts or portal structures that connect to the surface and provide access, egress and services to the underground operations such as electricity and ventilation. Tunnel shafts and portals may comprise inclined trenches that may be subsequently covered (cut and cover tunnels), horizontal drives from portals, and vertical or inclined shafts or declines.

These surface connections are potential vulnerabilities to the tunnel operations and may introduce risks from flooding or inundation, utilities, unknown artificial obstructions such as existing but unanticipated piled foundations, or from ground disturbance/interaction between the structures.

Shafts and portal structures may be vulnerable to flooding from adjacent waterways subject to intense rainfall, or in remote areas from natural terrain hazards such as landslides.

The shape, size and depth of a shaft depend on its application and purpose. Similar to a tunnel, these functional requirements, in view of the ground and groundwater conditions, will then inform the design approach and shaft construction method. Ground support systems should be adaptable to the chosen construction method and suitable for anticipated ground and groundwater conditions. Effective control measures must be implemented and maintained to ensure effectiveness, including by ensuring that the control measure is and remains fit for purpose, suitable for the nature and duration of the work, and installed, set up and used correctly.

The performance of the support system should be validated against the design using visual observation and monitoring data during construction.

Drainage systems should be designed to prevent water accumulation and erosion.

Excavation methods may include drill and blast, mechanical excavators, raise-boring machines, caissons (refer Chapter 10.3), shaft sinking machines or specially adapted TBMs. Accordingly, they are subject to the same rigorous safety considerations regarding risk management and provision of adequate controls as for tunnelling described elsewhere in this Code.

For further discussion of the issues, options and advantages and disadvantages of shaft construction methods, shaft support options, groundwater control options and permanent linings refer to ITA Report 36[4].

The risks associated with shaft construction and operation must be eliminated or, if that is not reasonably practicable, control measures must be implemented to minimise, so far as is reasonably practicable, those risks. SWMS must be developed for all high risk construction work. PCBUs should refer to *Code of Practice: Construction Work* and the WHS Regulation for further information.

9.2 Security edge protection & exclusion zones

All shafts, inclines, openings and edges associated with underground works must be secured to prevent unauthorised access, falls, and falling-objects hazards. Risks must be identified and should be managed through site-specific risk assessments and the application of the hierarchy of controls.

Edge protection

Effective edge protection must be provided at all open shafts, steeply inclined openings, and elevated edges. Edge protection systems must be designed, installed, inspected, and maintained to control risks and prevent persons, tools, materials, or equipment from falling.

4 ITA Report N° 36 / July 2025 TUST-D-24-02789R1 WG 23 Design & construction of shafts

Protective barriers should be erected around shaft collars and openings to:

- prevent people or materials from falling into the shaft,
- protect workers from falling-object hazards from activities above or adjacent to the opening, and
- prevent surface water ingress that could create flooding or secondary hazards.

Where edge protection systems are required to provide fall prevention, they should comply with applicable Australian Standards, including Australian Standard *AS 1657:2018 – Fixed platforms, walkways, stairways and ladders – Design, construction and installation* and Australian Standard *AS 4994.1:2023 – Temporary edge protection*, as relevant.

Exclusion zones

Exclusion zones should be established and maintained around shaft tops, vertical or steeply inclined openings, and areas where lifting, hoisting, or work at height is undertaken.

Exclusion zones should:

- be clearly defined and signposted,
- be physically barricaded where practicable,
- restrict access to authorised workers only, and
- be sized based on the risk of falling objects and the nature of work being performed.

Exclusion zones must be maintained to remain effective, reviewed and adjusted where work activities, equipment, or environmental conditions change, or when new hazards and risks are identified. Results of consultation may also indicate that a review of control measures is necessary. Control measures may also be required to be reviewed following a request from a HSR.

Falling objects

The risk of falling objects associated with work above shafts or within shaft environments must be managed and controlled in accordance with Part 3.1 of the WHS Regulation. Control measures may include:

- use of tool lanyards and tethering systems,
- securing of materials and equipment,
- installation of overhead protection or catch platforms,
- controlled lifting and hoisting procedures,
- restrictions on concurrent work above and below shaft openings, and
- exclusion zones.

Falling object controls must be incorporated into relevant SWMS and lifting plans.

Security of unattended openings

Where shafts, openings, or edges are left unattended, additional security measures should be implemented to prevent unauthorised access. This may include:

- secure covers designed to support expected loads,
- security fencing or locked barriers, and
- signage warning of risks of falls and falling objects.

Security measures must be maintained to remain effective and remain in place until permanent protection or closure is completed so far as reasonably practicable.

9.3 Safe access and egress

All shafts requiring access by workers must have safe means of access and egress during shaft construction and operation considering depth, frequency of use, and emergency requirements (refer Chapter 21).

Ladders, stairways, or mechanical hoists may be required to be used depending on depth and frequency of use.

Fixed access systems should be designed, constructed, and installed in accordance with Australian/New Zealand Standard *AS/NZS 1657:2018 – Fixed platforms, walkways, stairways and ladders – Design, construction and installation*. Temporary or modular access systems that comprise or incorporate scaffolding elements should also comply with Australian/New Zealand Standard *AS/NZS 1576.1:2019 – Scaffolding - Part 1: General requirements.*

Emergency escape routes should be planned and must be maintained once established, with consideration for smoke, fire, and flooding scenarios.

Control measures to prevent falls must be implemented e.g. fall prevention or protection systems (e.g. harnesses, guardrails etc.) if there is a risk of falling.

Lighting and communication systems must be installed to ensure visibility and coordination during access and evacuation.

Mechanical access systems such as hoists must be designed, operated and maintained by competent persons.

A secondary means of egress should be provided in case the primary method becomes unavailable, e.g. a ladder, a second crane or a purpose-built emergency egress device such as a winch and davit system.

9.4 Personnel and materials hoists

Personnel and materials hoist means a hoist —

(a) that is a cantilever hoist, a tower hoist or several winches configured to operate as a hoist, and

(b) that is intended to carry goods, materials or people.

Systems of work must be provided and maintained to minimise risks to health and safety of persons maintaining, inspecting, repairing or operating the plant.

Commissioning reports should be provided which include results of functional tests, installation checks and load tests. Ensure that the hoist is securely tied into the supporting structure at intervals not exceeding 6m, or in accordance with the manufacturer's or design specification.

Inspections and maintenance must be carried out in accordance with the recommendations of the manufacturer or a competent person. Records of maintenance, routine inspections and pre-operational inspections should be maintained. All maintenance and repairs must be carried out by a competent person.

Inspections must include checks of:

- interlocks,
- drive motors and over speed safety devices,
- limit switches,
- mast erection and ties,
- correct alignment of mast sections.

Ensure that:

- travel limiting devices that interrupt the power supply are installed at the top and bottom of the hoist mast,
- measures are provided to prevent the hoist car from disengaging from the mast in the event of failure of the guide roller or shoe, and
- each hoist has legible signage in the hoist car stating the rated capacity of the hoist, expressed as:
  - materials capacity (in kilograms or tonnes), and
  - maximum number of persons (typically calculated at 80kg per person).

Material only hoists should be clearly marked with “No Riders Allowed” signage.

Dual-use systems (for both personnel and materials) should have:

- separate operating modes,
- interlocks to prevent simultaneous use,
- emergency override systems.

Entrances to personnel and materials hoists must be guarded with gates or barriers and marked with high-visibility warnings. Landing gates and car doors are to be fitted with mechanical locking devices that are electrically interlocked with the hoist controls. Landing gates should only be capable of opening outwards toward the landing.

Ensure that the power supply to the hoist is clearly identified as being for hoist operation and on a separate sub circuit protected by a core balance earth leakage device (RCD).

Hoist operators must hold the relevant high risk work licence to operate the hoist. Refer to the following table:

Table 2: High risk work licence requirements for operating hoists

Hoist type	HRWL class
Personnel and materials hoist	HP and HM
Materials hoist	HM

Hoists with a platform movement exceeding 2.4 metres, designed to lift people require design registration.

9.5 Services

All services including ventilation, power, water, compressed air, lighting and communication should be clearly identified and securely attached to the shaft wall and protected from damage. Identification and colour coding of services and piping should be provided in accordance with Australian Standard *AS 1345-1995 - Identification of the contents of pipes, conduits and ducts*, to ensure hazards are readily recognisable and to support safe operation, maintenance, and emergency response.

10. Tunnel excavation and ground support

10.1 Overview

PCBUs must implement effective control measures to manage the risks associated with tunnel excavation and construction. Effective ground support is required to maintain control of the underground excavation to prevent collapse and ensure stability.

For the purposes of this Code two broad tunnelling excavation methods are described along with commonly used ground support methods:

- Conventional tunnelling includes drill and blast, roadheaders and other mechanical excavation methods. The method follows a cycle of excavation and support allowing for variable ground and complex geometries. It can offer programme and productivity advantages for shorter tunnels by utilising multiple working faces (headings) and is typically more labour intensive.
- Bored tunnelling using tunnel boring machines (TBMs), with or without a segmental lining, that are selected where tunnels are longer with a consistent cross section, such as for metro running tunnels, hydraulic conveyance or other utility tunnels. It is rare that a tunnel project is built by mechanised tunnelling alone and normally there will be a component of conventional tunnelling for functional requirements such as cross passages or for changes in geometry.

10.2 Tunnel Boring Machines (TBMs)

TBM selection

TBMs should be designed, specified, and selected to suit the full range of anticipated ground and groundwater conditions. TBM selection is a critical risk control measure and must be informed by a comprehensive geotechnical investigation, hazard identification, and risk control addressing both normal and reasonably foreseeable adverse conditions.

The safe use of TBMs requires competency at both corporate and individual levels, including in design, procurement, operation, inspection, maintenance, and emergency response. Following manufacture, TBMs should undergo factory acceptance testing (FAT). Commissioning should be carried out on site by constructing an initial length of tunnel under the supervision of the supplier and the Principal Contractor, to verify performance, operational controls, and safety systems.

There are two principal types of TBMs, distinguished primarily by their approach to ground support and face stability, which has direct implications for worker hazard and risk exposure:

Open Gripper TBMs

Open gripper TBMs are typically used in competent hard rock conditions. These machines do not provide continuous support to the tunnel face or ground and rely on the inherent strength of the rock mass. Ground support, such as rock bolts, steel sets, and shotcrete, are installed as required based on observed ground conditions.

The use of open gripper TBMs generally involves greater exposure of workers to unsupported ground, requiring robust procedures for ground assessment, face access, installation of temporary and permanent support, and protection against rock falls and instability.

Shielded TBMs

Shielded TBMs advance within a protective shield and use a segmental lining ring to provide continuous or near-continuous ground support. These machines are suitable for a wide range of ground and groundwater conditions and generally reduce direct worker exposure to unsupported ground. Shielded TBMs include:

- Hard Rock Shielded TBMs,
- Pressurised Face (Closed Face) TBMs, comprising:
  - Earth Pressure Balance Machines (EPBMs),
  - Slurry TBMs.

Pressurised or closed face TBMs maintain stability at the tunnel face by applying controlled pressure. EPBMs use excavated material to balance face pressure, while slurry TBMs use pressurised slurry. These systems introduce specific hazards, including those associated with pressure control, spoil handling, and maintenance activities. Where pressurised operation is required, additional controls must be implemented to manage risks related to compressed air, hyperbaric interventions, and system failure.

Hybrid or multi-mode TBMs may be capable of operating in more than one excavation or face support mode. The use of such machines requires careful planning, clear definition of operating modes, and additional hazard identification and risk control, particularly where transitions between modes are anticipated.

TBM selection must consider not only the expected geology but also potential variability, tunnel alignment, diameter, depth, groundwater conditions, and the need for face pressure control. The selected TBM should be capable of adapting to changing ground conditions and must be supported by an operational, inspection, and maintenance strategy that addresses foreseeable risks throughout the life of the tunnel works.

Sources of risk for TBM tunnelling

PCBUs should refer to European Standard *BS EN 16191 Tunnelling machinery – Safety requirements* for comprehensive information on TBMs and associated machinery. This European Standard addresses significant hazards and provides protective measures including:

- mechanical risks (e.g. moving parts, crushing, entanglement),
- electrical hazards,
- fire and explosion risks,
- hazardous atmospheres (e.g. gas monitoring within the TBM),
- noise and lighting,
- ergonomics and operator access,
- emergency stops and evacuation systems.

In addition, the design, manufacture, integration and modification of TBMs and associated machinery should comply with Australian Standard *AS 4024.1:2019 Series - Safety of Machinery*, which provides the overarching risk-based framework for hazard identification and risk reduction (including guarding, access, safety-related control systems, isolation/lock-out, and emergency stop functions) across all lifecycle phases (assembly, commissioning, operation, maintenance, and decommissioning).

Common hazards, risks and control measures for TBMs are summarised in Table 3 below, noting that European Standard *BS EN 16191 Tunnelling machinery – Safety requirements* provides TBM-specific protective measures while Australian Standard *AS 4024.1:2019 Series – Safety of Machinery* provides the general machinery safety principles and verification expectations to be applied to TBM plant and all associated machinery. Where TBMs are supplied to meet European Standard *BS EN 16191 Tunnelling machinery – Safety requirements*, compliance should be reviewed against Australian Standard *AS 4024.1:2019 Series – Safety of Machinery* to confirm suitability

for Australian WHS duties and site-specific interfaces (including ancillary plant such as conveyors, pumps, compressors, grout systems, ventilation plant, and segment handling equipment).

Mechanical and operational hazards are also described in Chapter 12 of this Code and further risk prompts provided at Appendix G.

Table 3: TBMs - Common hazards, risks and example control measures

Hazards and risks	Example control measures
Access restrictions	• Designing access ways, platforms, stairs and walkways in accordance with Australian Standard *AS 1657:2018 Fixed platforms, walkways, stairways and ladders – Design, construction and installation* or Australian/New Zealand Standards *AS/NZS 4024.2201:2024 (Part 1): Choice of fixed means and general requirements, AS/NZS 4024.2202:2024 (Part 2): Working platforms and walkways, AS/NZS 4024.2203:2024 (Part 3): Stairs, stepladders and guard rails,* and *AS/NZS 4024.2204:2024 (Part 2204) Fixed ladders*. • Providing fixed and interlocked guards where access to hazardous zones is required during maintenance. • Ensuring access openings are sized and positioned to avoid awkward postures and manual handling risks. • Designing TBMs so there is safe access to maintainable parts including access for screw conveyor repair or blockage. • Ensuring emergency plans are in place for recovery of injured people. • Planning exit routes.
Chemical exposure	• Limiting underground chemical storage. • Providing training and relevant information, such as Safety Data Sheets (SDS). • Ensuring chemical dosing, injection and transfer systems are enclosed or guarded to prevent inadvertent contact. • Designing plant to minimise manual handling of hazardous substances. • Applying the hierarchy of controls, including using PPE where required.

Hazards and risks	Example control measures
Crush areas around rams, grippers, walking feet or shields	• Applying Australian Standard *AS 1657:2018 Fixed platforms, walkways, stairways and ladders – Design, construction and installation* or Australian/New Zealand Standards *AS/NZS 4024.2201:2024 (Part 1): Choice of fixed means and general requirements, AS/NZS 4024.2202:2024 (Part 2): Working platforms and walkways*, *AS/NZS 4024.2203:2024 (Part 3): Stairs, stepladders and guard rails*, and *AS/NZS 4024.2204:2024 (Part 2204) Fixed ladders* and the hierarchy of controls to eliminate or physically separate personnel from crush zones where practicable. • Interlocking access doors and platforms so hazardous movement cannot occur while access is possible. • Interlocks and fail-safe control logic so loss of power or signal results in a safe state. • Using visual lock out devices and CCTV. • Ensuring operators can clearly see when grippers and pads are deployed and if there are obstructions.
Cross passage excavation	• Permit to Tunnel process (refer Chapter 10.4 of this Code).
Cutterhead interventions including hyperbaric interventions	• Planning interventions within areas of better ground or where ground treatment has improved conditions. • Designing cutterhead access systems to prevent inadvertent start-up during interventions (interlocks, trapped key systems). • Providing emergency stop devices accessible from all cutterhead intervention positions. • Designing for inherently safer maintenance, including minimising the need for worker entry. • Using a control procedure for cutterhead access and maintenance. • TBM tooling with rear loading cutters that can be undertaken under atmospheric pressure. • Restricting other maintenance when work on the cutterhead or cutterhead entry is in progress. • Ensuring adequate ventilation for the task.
Dust	• Isolating dust generating processes. • Using dust suppression, air filtration and scrubber units. • Using water sprays and dust suppression on conveyor belts.

Hazards and risks	Example control measures
Electricity	• Providing lockable, clearly labelled isolation points in accordance with Australian/New Zealand Standards *AS/NZS 4024.1603:2019 Safety of machinery series* and *AS/NZS 4024.1204 Safety of machinery – Electrical equipment of machines*. • Designing electrical cabinets and systems to prevent access to live parts without deliberate isolation. • Using cut-off switches and lock out systems. • Reporting actual or suspected damage to electrical plant including cables, immediately. • Implementing procedures for power failure. • Installing warning signs.
Face collapse including risks from changing ground conditions, mixed face, squeezing ground	• Careful selection and operation of TBM in view of credible range of ground and groundwater conditions to be encountered. • Use of Permit to Tunnel process and 'look ahead' and 'look above' probing and sensing methods.
Fire	• Designing fire detection, suppression and alarm systems to be fail-safe and operational under single fault conditions. • Segregating ignition sources from flammable materials where practicable. • Providing automatic fire detection and fire suppression systems (foam injection and water spray barriers). • Having individual electrical cabinet fire detection and suppression systems. • Installing aqueous film forming foam systems at locations where grease, oil and fuel lines and tanks are present. • Designing tunnel lining for fire durability. • Having detailed SWMS for hot works. • Implementing a hot work permit system. • Using fire resistant hydraulic fluid and fire resistant power cables for high voltage supply. • Use of fire retardant tail shield grease.
Gas accumulation	• Using gas detection and lock out devices. • Provide effective ventilation and extraction systems.

Hazards and risks	Example control measures
Ground support installation including access, ring build, segment handling	• Designing segment handling systems to prevent free fall under foreseeable fault or misuse conditions. • Guarding moving segment erectors and thrust rams to prevent inadvertent access to pinch points. • Providing clearly defined safe zones and exclusion areas designed into the plant layout. • Using remote control bolting. • Correctly operating segment feeder and handling devices including having operators visually check area before use. • Ensuring workers are competent in the use of segment handlers and follow manufacturer's instructions. • Ensuring the ring builder can visually see rams when moving them. • Use of exclusion zones so no work is done under unsupported ground. • Ensuring limbs are kept well clear of plant. • Inspecting installed ground support.
Heat exposure	• Supplying adequate and effective ventilation. • Designing ventilation and cooling systems as part of the TBM plant, rather than relying solely on administrative controls. • Supplying chilled drinking water. • Managing fatigue.
Irrespirable atmosphere including toxic gases	• Providing self-rescuers and checking their operation regularly. • Using emergency seals.
Tunnel collapse including ground and rock fall for open TBMs lining failure or support failure	• Use of Permit to Tunnel including 'look ahead' and 'look above' probing and sensing methods. • Robust design of ground support and quality assurance programs for lining.
Water ingress or inundation	• Refer to Chapter 11 of this Code. Further information can be obtained from BS 6164: *Health and safety in tunnelling in the construction industry Code of practice.*

The main areas of ground risk for TBMs are unanticipated ground conditions and/or groundwater conditions or poor management of the TBM in respect to the ground and groundwater conditions encountered. Ground conditions not anticipated by the design or TBM specification may result from either inadequate ground investigation and/or assessment of the risk of ground variability.

For larger diameter TBMs, the interaction of TBM operating parameters and the ground becomes increasingly complex as do the weight and power requirements of the TBM. The potential for geotechnical variability across a tunnel face also increases with scale, which increase the risk of encountering mixed face conditions. Risks may arise from not anticipating the need to change operational parameters before the issues become critical or not incorporating the feedback of data generated from the operation of the TBM.

Review of the data gathered by the TBM to make adjustments to drive parameters or undertake additional ground investigations should be undertaken as part of the Permit to Tunnel Process (refer Chapter 10.4) modified to suit a TBM operation.

Table 4: Pressurised face TBM hazards, risks and example control measures

Hazards and risks	Example control measures
Working with compressed air	Use of compressed air management plans and procedures[5]. • Designing pressure systems so uninterrupted pressurisation or depressurisation cannot occur. • Providing interlocked access systems that prevent entry when pressure limits are exceeded. • Ensure correct EPB and compressed air pressure calculations. • Select and train workers properly, including recovery protocols and use of hyperbaric chambers.
Incorrect Earth Pressure Balance (EPB)	• Verify EPB pressure calculations. • Providing automated monitoring, alarms and interlocks where EPB parameters exceed safe operating limits. • Designing control systems so loss of sensor input results in a safe operational state. • Monitor ground conditions and adjust EPB settings accordingly.
Working with high pressure slurry	• Guarding rotating and pressurised components to Australian/New Zealand Standards *AS/NZS 4024.1601:2024 Safety of machinery – Guards* and *AS/NZS 4024.1801:2025 Safety of Machinery – Safety distances to prevent danger zones being reached by upper and lower limbs*. • Providing emergency stop devices at slurry handling locations. • Designing slurry systems to prevent line opening under pressure. • Establish communication protocols at both ends during pigging of lines. • Conduct separate risk assessments for slurry tasks.

Poor maintenance of elements such as cutter tools, bearing oil lubricants or tail seal brushes all may have health and safety risk implications.

5 AS 4774.1-2003: Work in compressed air and hyperbaric facilities and ITA WG5 Health and Safety in Works Guidelines for Good Working Practice in High Pressure Compressed Air ITA Report 10 March 2018

Other health and safety risks may arise from:

- damage to segments or gaskets,
- loss of effectiveness of seals at the back of the TBM,
- flotation under shallow cover,
- face blow-out to surface in the case of pressurised face (closed face) TBMs during operation or maintenance in low cover situations,
- over-excavation leading to face collapse especially during launch and receival of TBMs,
- unanticipated voids or fault zones and inundation,
- excessive wear or damage to the cutterhead requiring interventions from surface,
- inundation via inability to close earth pressure balance screw conveyor,
- geological materials and airborne contaminants such as silica and naturally occurring asbestiform minerals or hydrocarbons,
- breakouts from the segmental lining into soft ground or incomplete sections of ground treatment,
- drilling through the segmental lining into soft ground,
- planned and unplanned face interventions especially those requiring compressed air[6].

TBM design should include a range of safety features including:

- automatic fire detection with foam suppression systems and water spray barriers,
- storage facilities for safety equipment like breathing apparatus, self-rescuers, first aid and resuscitation equipment,
- audible and visual pre-start warning systems on major moving parts,
- interlocking isolation systems,
- isolation locks on major moving parts and electrical and pressure systems,
- conveyor belts with pull cords for emergency stop,
- guard rails on moving machinery like conveyor belts and pumps,
- emergency lighting on walkways,
- continuous tunnel environmental monitoring giving direct readout to the control cabin with alarms at key locations including above ground,
- closed-circuit television in the control cabin with cameras fitted in the cutterhead during interventions, in areas where spoil is discharged onto the conveyor belts into the muck skips and in areas where locomotives are moving within the confines of the TBM,
- effective communications systems between the control cabin and critical locations,
- air-conditioned control cabins, including high efficiency particulate air filtering and/or positive air pressure,
- electrical isolators and lock-off devices fitted on items containing dangerous moving parts,
- if mucking uses locomotives, traffic light systems at the rear of the trailing gantry to control the shunting of rolling stock during segment unloading and muck skip filling,
- walkways with non-slip surfaces, fitted with handrails with headroom along the entire TBM length,

6 Refer ITA WG5 Health and Safety in Works Guidelines for Good Working Practice in High Pressure Compressed Air ITA Report 10 March 2018

- access from one trailer to the next without having to step into the segment unloading area or ring build area,
- working platforms in build areas should allow segment erector operators maximum visibility,
- lifting devices for segments and other equipment secured against free fall,
- back-up power supplies for a main power failure for critical safety systems.

10.3 Conventional tunnelling

Overview

This method is highly adaptable to large and varying tunnel geometries and geological conditions, and suitable for complex structures, alignments or smaller-scale projects.

Mechanical excavation methods, including the use of excavators, roadheaders and hydraulic breakers, and drill and blast should be selected, operated, and maintained in order to minimise risks to health and safety.

Risk assessments should consider:

- ground stability and support requirements,
- interaction with other plant and personnel,
- potential for remote operation,
- vibration, noise, and dust emissions, and
- fire and smoke (refer Chapter 22 of this Code).

Drill and blast

Drill and blast tunnelling is a conventional excavation method used primarily in hard rock conditions. It involves drilling holes into the rock face, loading them with explosives, and detonating to fracture the rock. After blasting, the broken material (muck) is removed, and ground support systems such as rock bolts, mesh or sprayed concrete installed as required by the design.

Blasting requires careful planning and control to manage ventilation and other safety risks, particularly the location of workers relative to the blasting face. The products of combustion from a blast may include oxides of nitrogen, ammonia, nitric acid, carbon monoxide and carbon dioxide. The use of explosives in NSW requires a user license for blasting explosives authorising purchase, storage, use and disposal of explosives from SafeWork NSW and is subject to existing legislation, standards and codes of practice.[7]

Following blasting or re-entry to the tunnel face, the walls, sides, face and support systems should be inspected before normal work commences.

Ground support in accordance with the Permit to Tunnel process should be provided as required and as soon as practicable after scaling (refer Chapter 10.4 of this Code) to maintain the overall integrity of the rock mass and to prevent rock falls. This may consider face support in case of spalling ground.

Manual excavation

Most tunnelling work is partly or totally mechanised but this may not always be possible for smaller scale excavations. Excavating manually should be limited to situations where access and or other constraints prohibit mechanisation and the options regarding the need for manual excavation should be considered during design development.

7 These include Explosives Act 2003, Explosives Regulation 2024, Australian Explosives Code, Australian Standard AS 2187, Australian Standard AS 4326, Australian Dangerous Goods Code.

The hazards of this type of work which must be managed include those for larger scale conventional tunnels but requiring specific attention to confined space work, noise, hand-arm vibration, manual handling, dust, work at height and heat. Short shifts and/or frequent rotation of persons around different tasks should be considered as part of the controls, in order to limit exposure to noise, vibration and manual handling risks.

Adequate safe working space and, as necessary, working platforms must be provided so far as reasonably practicable.

Sources of ground risk for conventional tunnelling

These include:

- unanticipated changes in ground and groundwater conditions leading to instability or inundation,
- failure of ground support due to underestimation of demand from ground loads or from excessive introduced loads (e.g. grouting) or from material deficiencies, or ground swelling,
- geological materials and airborne contaminants such as silica and naturally occurring asbestiform minerals or hydrocarbons.

Table 5: Ground behaviour[8]

Descriptor	Potential failure modes/scale/comment
Stable	Potential for small scale gravity-induced falling of blocks during excavation. Does not threaten overall tunnel stability but requires risk controls.
Block fall under gravity	Discontinuity-controlled, gravity-induced falling and sliding of blocks; occasional local shear failure on discontinuities.
Stress induced failures (including spalling)	Stress-driven failure mechanisms including rock spalling, slabbing and strain bursting, influenced by in-situ stress levels, excavation geometry, discontinuities, and local rock mass strength and stiffness variations. High in-situ stresses, such as those encountered in NSW, may also adversely affect installed ground support.
Rock burst	Sudden and violent failure of the rock mass, caused by highly stressed massive rocks.
Ravelling ground	Ravelling of dry or moist, intensely fractured, poorly interlocked rocks or soil with low cohesion.
Flowing ground	Weak ground and groundwater flow combine to erode and transport external ground into excavation.
Mixed ground/heterogeneous ground	Variable behaviours, stresses and deformations due to heterogeneous ground (soil/rock or in combination) strength and stiffness, influence of faults or intrusions.

8 For additional guidance, refer Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation Austrian Society for Geomechanics (2010)

10.4 Excavation support performance: the Permit to Tunnel

The support system performance should be validated by observations[9] of ground, groundwater, and the installed support itself. This validation should involve:

- Review of ground and groundwater data that enabled hazards and risks to be identified and assessed by the design. This review should include assessment of the limitations of the site investigations and residual uncertainty associated with the available data. Subject to risk assessment this may inform the requirements for further investigations prior to, or concurrent with construction.
- A design with:
  - Support types that cover the range of anticipated ground and define the range of system behaviour. Designs should present selection criteria for a range of ground support types and excavation sequencing to match specific ground conditions and anticipated behaviour;
  - Definition of the monitoring and other observational requirements that are required to validate the design, i.e. confirm that behaviour is within the limits of the design; and
  - Any provisions for additional investigations if required - for example ahead of and above the tunnel face in anticipation of transition to a zone of different behaviour if such uncertainty is a material risk to the design.
- The use of a reliable and accurate system of monitoring during construction suited to the method of excavation and design and construction.
- Limits ('trigger values') and the actions associated with them, established by the design to provide an integrated set of responses in relation to the observed behaviour of the support system. A TARP should include modifications anticipated by the design in relation to monitoring frequency, additional support or limiting further excavation. Whilst serviceability considerations and third party implications may have more stringent limits, a 'safety critical trigger' level should be set to avoid exceeding the ultimate capacity of the support system and thereby ensure stability and excavation risk control.
- Regular review, with frequency determined by the TARP of the monitoring data by an integrated project team from the designer, contractor and Client Organisation as required by risk assessment.
- Quality assurance via regular independent auditing, review and quality control.

A Permit to Tunnel (PTT) is commonly used in NSW as a means of managing construction safety risks and quality underground. Depending on the nature and level of risk, a PTT process should include the following elements:

- Daily or more frequent (as required by risk assessment) review by competent personnel of geological and monitoring data, excavation staging and support installation against the requirements of the design and the anticipated system behaviour.
- Review of the performance and quality requirements of the applied ground support from the design (including any additional investigation, pre-support or ground treatment applied ahead of the tunnel face) construction sequence and advance length.
- Entry requirements and exclusion zones for work and any project specific definition of 'supported and unsupported ground' for example if these are affected by time requirements for support measures to gain strength for currently active excavation faces.

9 The use of observation or observational in this chapter and elsewhere in the document does not imply the use of an 'observational method of design' (refer Appendix F).

The conditions at the face should be established and logged in accordance with any site-specific ground classification scheme and if required should be combined with probing or other investigation methods ahead of and above the tunnel face ('look ahead'). This update of ground conditions should inform the PTT, and enable effective interventions to control ground conditions, groundwater flows and the potential for inundation and generally minimise ground risks and maintain excavation control.

As the PTT is a risk management and procedural quality control document, it does not modify or replace the certified design. However, a PTT may identify conditions or circumstances that indicate the need for a design change and be progressed through a formal design change management process (refer Chapters 3.5 and 4.2 of this Code).

Where a PTT identifies conditions outside the design assumptions that may threaten stability or affect excavation control, pre-planned actions should be implemented to make the excavation safe and, where necessary, to stop further excavation.

Once a design change has been formally assessed and approved (refer Chapter 4.2) the PTT may be updated to implement the approved change and release any associated hold points. In this way, excavation and support activities are subject at all times to a duly approved design, and control of the excavation is maintained.

If PTT is used, PCBUs must check the implementation of the design and monitor performance and implementation of the PTT process to ensure that the control measure is effective, maintained, fit for purpose, suitable for the nature and duration of the work, and is used correctly.

10.5 Cross passages, sumps and ancillary excavations

Cross connections between parallel tunnels or adjacent shafts are secondary tunnelling activities. These are typically but not always undertaken using conventional tunnelling methods but can also be undertaken using small diameter TBMs and segmentally lined box jacks.

Cross passages can be used for permanent or temporary plant and equipment, or to facilitate movement between two tunnels. Necessarily, they involve more complex geometry and the opening of the ground behind the initial lining of the first tunnel or shaft, and this may involve significant ground or support instability and inundation risks.

Ground and support risks for all cross passages, sumps and ancillary excavations should be controlled by design and by using the PTT process described above. This should include any exclusion zones required around any 'break-in' or non-excavation locations.

10.6 Pipe jacking

Pipe jacking is a trenchless method of tunnel construction whereby pipes are hydraulically pushed through the ground from a drive shaft to a receival shaft (or from one tunnel to another as an ancillary structure or cross passage). It is suitable for small diameter pipelines and tunnels and is commonly used for utility installations.

Foreseeable hazards of pipejacking include hazardous manual tasks, noise, heat, vibration and confined space work. These hazards must be identified, and risks eliminated or minimised so far as reasonably practicable. There must be adequate space provided to allow a safe means of access and egress along with adequate working space within the pipejack if worker entry is envisaged for maintenance.

The minimum diameter required for construction may be determined by the construction methodology, controls required and emergency scenarios rather than by consideration of the requirements for or the intended use of the pipejack alone.

The risks associated with worker intervention in the mechanical excavation process should be carefully considered and the physiological demands of small diameter working and ability of workers to self-rescue or to be rescued should be carefully considered and documented.

Table 6: Pipejacks and microtunnel TBMs - hazards, risks and example control measure

Hazards and risks	Example control measures
Injuries when maintaining or repairing the micro-TBM	Minimum pipe diameters to suit anticipated maintenance and repair procedures and recovery of injured personnel/emergency egress. Using lock outs and isolation procedures. Using camera and communication systems. Setting up exclusion zones during operation and maintenance. Checking emergency planning is in place including planning of safe retreats.
Loss of control of the micro-TBM	Real-time monitoring: Use of telemetry systems to monitor TBM position, thrust, torque, face, plenum or slurry pressure, and cutterhead speed. Steering protocols: Clear procedures for steering adjustments, including allowable deviation limits and correction methods. Use of competent operators: Skilled personnel trained in microtunnelling operations and emergency procedures.
Damage to pipes such that the excavation cannot advance	Design verification: Ensure pipes are designed for expected jacking loads and ground pressures. Quality assurance: Inspection and testing of materials and dimensional tolerances. Lubrication systems: Use of bentonite or polymer to reduce friction and jacking forces. Installation controls. Alignment monitoring: Continuous tracking of segment position and orientation during installation. Controlled jacking pressure: Monitoring and limiting jacking forces to avoid overstressing segments. Proper bedding and joint sealing: To prevent point loading and water ingress.
Failure of jacking and pipe handling system	Assessing and verifying temporary lifting design requirements and procedures. Inspecting pipes, seals and packing before pushing. Using designed lifting systems.
Disconnecting and reconnecting electric and air pressure services	Use of controlled procedures for electrical installation, energisation, isolation and disconnection. Checking air hoses are connected correctly and use of whip restraints.
Shaft access and egress	Using access control, camera and communication systems. Checking emergency planning is in place including planning safe retreats.
Crush areas including near pipe jacking rams	Setting up exclusion zones during operation. Checking body parts are clear when jacking pipes.

10.7 Commonly used materials and support systems

Sprayed concrete or shotcrete

Shotcrete support is used across a wide range of ground conditions from relatively soft ground, soils such as clay or weathered rock, to weak and hard rock applications. Shotcrete is a flexible and commonly used ground support and can incorporate fibres, steel mesh, steel sets, lattice arch girders and even deformable elements in heavy 'squeezing' ground.

Shotcrete is often used to provide initial support in advance of a permanent lining and is also used as a composite structural material for permanent support as it can be sprayed in layers to suit capacity requirements and excavation staging.

Profile control requirements, the thickness and smoothness of the sprayed concrete layers and the extent of any exclusion zone to be observed whilst strength is gained should be established from specifications and shotcrete trials and other requirements of the lining designer. Shotcrete trials should develop the shotcrete mix designs to be used in the works, and the quality control and assurance requirements for construction that may include trial panels, laboratory and in-situ tests.

Operators must be trained and competent in shotcrete application.

An exclusion zone should be established during the excavation and the spraying operations to prevent exposure to hazards from unsupported ground or from falling shotcrete affected by ground loads or groundwater. An exclusion zone of suitable size should be established around freshly sprayed areas until the young shotcrete has gained sufficient strength and any rock bolts (if required) have been installed. Re-entry times should be determined by the design and risk assessment.

Cast in situ linings

Cast in situ linings involve placing concrete directly into formwork within the tunnel.

Formwork systems' strength and rigidity should be sufficient to withstand the loads imposed by wet concrete and handling operations. Inadequate formwork can lead to construction difficulties, unsafe conditions, and poor-quality linings. Formwork should not be removed or modified until the concrete has achieved the specified strength. Where formwork is erected manually, it should be designed to be lightweight and easy to handle.

Concrete should be specified, produced, transported, and tested in accordance with:

- The design requirements including any project specific requirements and specifications of the Client Organisation if available,
- Australian Standard *AS 1379-2007 – Specification and supply of concrete*,
- Australian Standard *AS 1012 series – Methods of testing concrete*.

Formwork should be designed and constructed in accordance with Australian Standard *AS 3610.1:2018 – Formwork for concrete* and relevant structural design actions under the Australian/New Zealand Standard *AS/NZS 1170 series – Methods of testing concrete*. PCBUs should refer to *Code of practice: Formwork* for further information.

The use of concrete pumps and placing booms should comply with Australian Standard *AS 2550.15:2019 – Cranes, hoists and winches - Safe use, Part 15: Concrete placing equipment*.

Segmental linings

Segmental linings consist of pre-cast concrete, steel or less commonly spheroidal graphite iron (SGI) assembled within the tunnel. They are typically used with tunnel boring machines (or shafts) in rings and provide rapid installation and rapid high structural integrity.

Necessarily, segmental tunnel and shaft linings have multiple joint surfaces that may enable water and fine material into the tunnel or shaft without effective controls. Minimisation of damage to segments and control of water and fines ingress (especially in soft silty sands under water pressure) is critical to ensuring the health and safety of workers.

Segment design for TBMs must consider ring length limitations due to gantry frame access and tunnel clearance and segment taper and width, which can affect TBM performance, especially on curves. Handling and installation risks may be controlled by using mechanical means, vacuum pads or purpose-designed lifting frames. Designers and installers must consider lifting, transport, storage and installation requirements.

Risks with handling segments must be managed to ensure that risks are minimised i.e. that the segments cannot shift, fall, or become dislodged during storage, lifting, transport, or installation. Specific care should be taken to avoid abnormal loads that could compromise segment integrity.

A SWMS must be prepared for the installation of segments. SWMS preparation and the installation of the segment should be planned and supervised by competent persons.

Operators of installation equipment should have a clear view of the operation, and shove ram thrust should not be the sole support method. Segments should be positively secured using bolts or dowels or other means determined by the design.

Erection gantries must provide a safe working platform and safe access and egress. This should be in accordance with Australian Standard *AS 1657:2018 – Fixed platforms, walkways, stairways and ladders*.

Rock bolts and dowels

Rock bolts and dowels are used in a variety of ground conditions from weathered and faulted rock to hard rock. They are typically installed to provide immediate reinforcement by transferring load from potentially unstable ground to more competent strata and may be used in conjunction with other support systems such as shotcrete or mesh.

- Rock bolts are tensioned or grouted elements either steel (rigid bar or cable) or fibre glass elements installed in drilled holes to reinforce the rock mass and control movement.
- Dowels are passive reinforcing bars, usually fully grouted, that provide resistance to displacement and enhance overall ground stability.
- Split set bolts consist of a slotted steel tube driven into a slightly undersized hole, creating frictional contact with the rock over the full length of the bolt.
- Swellex bolts are hollow steel tubes inserted into a borehole and expanded using high-pressure water, conforming to the borehole shape and providing frictional anchorage.

An exclusion zone should be established during drilling, installation, and any tensioning operations to prevent exposure to hazards from unsupported ground, falling rock, or movement of plant and materials.

The length, diameter, spacing, and installation method for bolts and dowels should be determined from project and design specifications, site trials, and any relevant laboratory or in-situ testing, as well as the requirements of the ground support designer.

An inspection and testing plan for installed bolts and dowels must be established, with consideration given to the specifications, to verify correct installation and load capacity, to ensure the control is effective and fit for purpose. Inspection and testing plans may specify pull testing or other verification requirements. In high stress environments drillholes may require inspection using endoscopes prior to installation of the rock bolt.

Any defects or non-conformances with the quality assurance system should be considered for materiality with respect to excavation safety and control. This may extend to remedial works controlled by the PTT process with impacts upon further staging of excavation and/or additional support installation.

Steel sets and lattice arch girders

Steel sets and lattice arches are structural support elements used in underground excavations to provide ground support. These can be used to help maintain the shape of the excavation and distribute ground loads. Steel sets are typically higher capacity and stiffer than lattice arches. Lattice arches are always integrated within a shotcrete lining.

SWMS must be developed for the handling, assembly, and installation of arches to prevent exposure to hazards from unsupported ground, falling objects, or movement of heavy components and equipment.

The size, spacing, and installation sequence of arches should be established from project specifications, site trials, and any relevant laboratory or in-situ testing, and the requirements of the ground support designer.

To ensure effectiveness of control measures all installed arches must be inspected, tested and maintained. This will include checking for correct alignment, secure connections, and overall stability. Significant non-conformances will require review and revision of the control measures by Designers and PCBUs and may require rectification before further excavation or support installation proceeds.

Canopy tubes

Canopy tubes, also referred to as pipe umbrellas or spiling systems, are pre-support ground improvement elements installed ahead of an excavation to provide temporary support to the ground and control deformation. They are typically used in weak, fractured, or variable ground conditions, particularly at tunnel portals, shallow cover, or in areas of poor stand-up time.

Canopy tubes consist of steel pipes or tubes installed radially or sub-horizontally above the excavation profile and are commonly grouted to improve load transfer and ground stiffness. They act to form a temporary support canopy that reduces ground movement and limits the risk of collapse during subsequent excavation and installation of permanent support. SWMS must be developed for drilling, handling, grouting, and installation of canopy tubes to manage hazards associated with unsupported ground, overhead work, pressurised systems, drilling operations, and the handling of long and heavy steel components. Particular consideration must be given to exclusion zones, protection from falling objects, and the control of drilling fluids or grout returns. The design of canopy tube systems, including tube diameter, length, spacing, overlap, inclination, grouting method, and installation sequence, must be determined by the ground support designer based on ground conditions, anticipated loads, excavation method, and relevant site investigations, trials, or monitoring data.

Installation must be carried out in accordance with the approved design and SWMS and should be in accordance with the PTT if a PTT process is used. Where installation deviates from the design assumptions, or where unexpected ground conditions are encountered, the works must be reviewed by the ground support designer before further excavation proceeds.

Installed canopy tubes must be inspected to confirm correct alignment, embedment, grouting effectiveness, and overall integrity. Any significant non-conformances or damage must be assessed by Designers and PCBUs to determine their impact on ground support performance and whether rectification or supplementary support is required prior to continuing excavation.

10.8 Waterproofing systems

Waterproofing systems may be required as a control measure to prevent water ingress into the tunnel. Waterproofing can increase the durability and performance of tunnel systems, fixtures and fittings.

If waterproofing is required, the waterproofing level and system must be specified by the design for each construction and operational stage. If conditions change the control measures must be reviewed and revised as necessary to ensure the controls are effective and fit for purpose.

Methods of waterproofing include sheet membranes and associated geotextiles, chemical coatings (spray membranes) and joint sealants.

To assist in minimising fire risks, membranes should be selected that have the following properties: self-extinguishing; not sustain burning after removal of the ignition source; not propagate flame; and not produce flaming droplets.

Spray-applied waterproofing membranes may be available in powder or liquid forms and may contain reactive or hazardous chemicals, including:

- Isocyanates (e.g. MDI or TDI), which are known respiratory sensitizers and may cause occupational asthma; some are classified as suspected carcinogens.
- Solvents, including volatile organic compounds (VOCs), that may cause neurological effects, respiratory irritation, and contribute to poor underground air quality.
- Epoxy or bituminous compounds, which may contain skin and eye irritants, sensitising agents, or other toxic additives.

The use of these hazardous chemicals pose risks that must be controlled. These risks include worker exposure through inhalation, skin contact, and environmental exposure, especially during application where work methods may increase airborne concentrations. For information on hazards, risks and controls refer to the relevant Safety Data Sheets for the substance.

Where spray applied membranes are used effective controls must be used to prevent worker exposure.

10.9 Re-profiling

Re-profiling involves reshaping the tunnel surface to meet design geometry or improve stability.

It may include trimming overbreak or correcting misalignment.

Given that installed ground support is being modified by the re-profiling excavation, the control measures must be reviewed and, as necessary, revised.

10.10 Scaling

Scaling in tunnelling is the critical safety process of removing loose, unstable rock from the roof, face, and sidewalls to prevent rockfalls. Risks from scaling activities must be controlled in accordance with Part 3.1 of the WHS Regulation and a SWMS must be prepared. Other controls may include documented control procedures, defined exclusion zones, selection of suitable plant to be used, use of remotely operated plant, suitable overhead protection systems, and operator and worker protection from the risk of uncontrolled falling objects.

Scaling work should be carried out systematically, working towards the face. Inspection, monitoring and testing requirements must be established. Scaling work and inspections should be carried out regularly by competent persons. Scaled areas should be checked by a competent person to ensure that it is safe to permit other work to proceed in the area.

10.11 Geotechnical instrumentation and monitoring

Geotechnical monitoring provides data on ground behaviour and ground support performance.

Instruments may include extensometers, inclinometers, piezometers, strain gauges, fibre optics, optical survey and laser distancing and scanning instruments used for convergence monitoring.

Monitoring requirements during construction must be developed, implemented and maintained. Consideration in developing these requirements can be obtained from the design and risk assessments.

To ensure geotechnical monitoring systems are effective, fit for purpose, reliable and accurate, they must be maintained. This maintenance should include regular calibration.

PCBUs must provide the information necessary to protect all persons from risks to their health and safety arising from work carried out as part of the conduct of the business or undertaking, e.g. the data and results from geotechnical monitoring. The provision of this information is required to ensure control measures are effective, and maintained to remain effective, and to identify and control any new or evolving hazards and risks.

11. Groundwater

11.1 Groundwater controls

Overview

During construction of shafts and tunnels it may be necessary to revise work methods to effectively control the risks from groundwater. Any system of groundwater control should consider the consequences of system shutdown or failure and the reliability and resilience of any back-up systems.

Groundwater control by reducing ground permeability

These methods reduce the ability of water to flow through the ground.

- Permeation Grouting injects fluids (cementitious grouts or acrylic resins) under pressure to fill voids or other permeable features of the ground and can be used to reduce permeability and improve strength outside the tunnel.
- Jet grouting and soil cement mixing are forms of ground improvement that cuts and mixes the ground with cement to form overlapping cylinders of engineered ground of defined strength and permeability that form a barrier to groundwater flow.
- Ground freezing uses either calcium brine or nitrogen in closed systems of injection pipes to freeze the groundwater in-situ. As ground freezing is extremely specialised, to ensure it is an effective control measure, the effects of the heave associated with the expansion of water during freezing must be integrated with structural designs. It is the least commonly adopted method for groundwater control.

All methods should be undertaken by competent persons. Rigorous validation and monitoring is required throughout construction works to ensure the effectiveness of control measures.

The use of groundwater control methods may be a source of risk to the tunnelling operation, and ground support systems. These risks should be acknowledged and must be controlled and may be integrated with the PTT process (refer Chapter 10.4).

Compressed air tunnelling

Compressed air working (hyperbaric works) is a means to counterbalance groundwater pressures to reduce flows to manageable levels. Hyperbaric works (cutterhead interventions) are sometimes required in the maintenance of TBMs, and compressed air is used as a short-term measure to limit groundwater flows during such an operation. PCBUs should have regard to Australian Standard *AS 4774.1:2026 Work in compressed air and hyperbaric facilities - Part 1: Work in tunnels, shafts and caissons*.

High Pressure Compressed Air is “work in compressed air at pressures above historical statutory limits in the range 3 to 4 bar (gauge), and which involves the use of breathing mixtures other than compressed natural air and can involve the use of saturation techniques”[10].

In managing risks associated with compressed air tunnelling, duty holders should have regard to recognised international guidance, including the International Tunnelling Association (ITA) Report No. 10: *Guidelines for Good Working Practice in High Pressure Compressed Air* (latest edition), where relevant to the nature and conditions of the work.

10 ITA Report No. 010 – Guidelines for Good Working Practice in High Pressure Compressed Air

Dewatering systems

Dewatering approaches reduce groundwater pressures by drainage ahead of an advancing tunnel or a cross passage.

Dewatering using pumps or vacuum wells may be done from the surface or passive drains using simple probe holes drilled ahead of the tunnel face may be utilised underground.

All dewatering activities, including the excavation of any tunnel or opening that allows the ground to drain has the potential for risk from ground settlement above.

Health and safety risks may be associated with dewatering contaminated land or tunnelling in proximity to land uses such as tanks for underground hydrocarbon storage (refer Chapter 11.4 below).

11.2 Tunnel drainage

Effective tunnel drainage is an essential control measure to maintain safe working conditions. Drainage systems should be designed to manage both groundwater ingress and surface water runoff, accounting for:

- geological and hydrogeological conditions,
- tunnel gradient and alignment including invert cross fall,
- anticipated water inflows during excavation and operation.

Drainage infrastructure may include:

- collection sumps and pumping systems,
- graded invert channels or pipes to direct water to collection points,
- redundancy in pumping systems to manage peak inflows or pump failure.

Drainage systems must be maintained, this includes taking steps to prevent blockages, overflows, or flooding, such as:

- regular inspection and cleaning,
- monitoring of pump performance and water levels,
- emergency backup power for critical drainage equipment.

The risks to persons from contaminated water (e.g. from hazardous chemicals, drilling fluids, fuel spills etc.) must be identified and subsequently controlled. This may be done through containment or treatment and in accordance with environmental regulations.

11.3 Inundation

Inundation refers to the uncontrolled entry of water and flowable materials (such as silt and sand ‘running ground’) into a tunnel or cross passage, which can pose serious risks to worker safety, plant and equipment, and stability.

Particular care to identify potential sources of inundation is required in the design and planning phase. Potential sources of inundation include:

- aquifers or water-bearing strata or soils,
- proximity to rivers, lakes, or the sea,
- surface water drainage patterns,
- existing underground works that have the potential to be flooded, or
- dams.

Control measures may include:

- detailed ground investigations,
- probing ahead and above the excavation face,
- improvement of ground strength,
- reduction of ground permeability or other ground treatment,
- bulkheads or water-tight doors in high-risk areas,
- continuous water ingress monitoring systems,
- changes to the alignment,
- emergency pumping capability.

Indications of early-stage inundation or inrush might include the following:

- unusual strata/ground behaviour,
- changes in ground water flow,
- change in water quality, i.e. colour, suspended solids, chemical analysis,
- release of irrespirable atmospheres or flammable gases into the ventilation system,
- significant unexpected decrease in surface or other water.

Emergency response plans (refer Chapter 21) must be developed and should address:

- rapid evacuation procedures,
- communication protocols,
- location and access to refuge chambers or safe zones,
- alternative exit routes and refuge locations should main exits be blocked,
- use of transport considering inrush and inundation conditions,
- special equipment to assist in exit or rescue e.g. emergency pumps.

Training and drills should be conducted regularly to ensure all personnel understand the inundation response procedures.

PCBUs should refer to the NSW Trade & Investment Mine Safety *Code of practice: Inundation and inrush hazard management* for detailed requirements.

11.4 Contaminated land and ground water

A duty holder, in managing risks to health and safety, must identify reasonably foreseeable hazards that could give rise to risks to health and safety. The hazards arising from the presence and migration of chemical, biological, and microbiological contaminants should be initially assessed through a study of previous uses of the site and surrounding area. This assessment should inform the scope and extent of ground investigation, hydrogeological assessment, and laboratory testing. The data obtained should be sufficient to quantify risks associated with potential occupational exposure during construction, including any risk controls and/or requirements for further testing of encountered conditions, impacts on the structure over its design life, and environmental impacts.

The presence of chemical contaminants associated with historical or existing industrial land uses, including gas production, metal processing, and chemical industries, must be considered. Contaminants to be assessed should include acid sulphate soils, hydrocarbon fuel residues, tar and tar residues, polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), heavy metals, and organic solvents.

Consideration should be given to microbiological contamination, including pathogenic organisms such as Escherichia coli and Legionella species, particularly where groundwater, surface water, or impacted soils may enter the tunnel environment. Where groundwater inflows are anticipated, the potential for the presence of hydrogen sulphide (H_2S) should be assessed, due to its acute toxicity, corrosive properties, and potential to accumulate in confined underground spaces.

While contamination may be present in both ground and groundwater, contaminated groundwater plumes should be expected to extend beyond the immediate source area and may migrate along preferential pathways. The potential extent and behaviour of such plumes must be considered to enable hazards to be identified, and risks eliminated or minimised so far as reasonably practicable.

12. Machines and plant safety

12.1 General

PCBUs should refer to the following codes of practice for further information:

- *Code of practice: Managing the risks of plant in the workplace*
- *Code of practice: Moving plant on construction sites.*

PCBUs must ensure workers or other persons using plant in a workplace, are provided with information, training, instruction and supervision as necessary to protect them from risks arising from the use of the plant.

Systems that support plant safety should include the clear definition and management of operational plant zones. Plant zones should be established through risk assessment, documented in Safe Work Method Statements (SWMS), and clearly applied and communicated on site. The following plant zones typically apply:

- plant-only zones,
- plant operating and restricted personnel zones,
- plant hazardous zones.

Effective communication systems, such as two-way radios, visual signals, or other methods, should be used to coordinate activities where plant operates in proximity to other work or where simultaneous operations occur.

Plant and equipment should be operated in accordance with the manufacturer's instructions, within their design limitations, and in compliance with site-specific procedures. This includes the implementation of any controls identified through risk assessment(s).

12.2 Mobile plant

The WHS Regulation requires PCBUs to manage risks associated with powered mobile plant, including overturning, falling objects, operator ejection and ensuring the plant does not collide with any persons or things. PCBUs should also refer to the *Code of practice: Moving plant on construction sites* for further information.

Control measures (such as roll-overprotective structures (ROPS) and falling object protective structures (FOPS)) must be implemented where these risks cannot be eliminated.

Where risks cannot be eliminated, PCBUs must implement control measures in accordance with the hierarchy of controls, giving priority to substitution, isolation, and engineering controls. PCBUs must consider various control options and choose the control that most effectively eliminates the hazard or minimises the risk in the circumstances. This may involve a single control measure or a combination of different controls that together provide the highest level of protection that is reasonably practicable.

Administrative controls and PPE are the least effective at minimising risk because they do not control the hazard at the source and rely on human behaviour and supervision. These control measures should only be used:

— to supplement higher level control measures (as a back-up)

— as a short-term interim measure until more effective ways of controlling the risk can be used,

or

— when there are no other practical control measures available (as a last resort).

In addition to the common causes of moving plant incidents, PCBUs must identify any other site-specific hazards for each individual site and eliminate or minimise these risks e.g. provision of adequate lighting to ensure visibility of plant, pedestrians, access routes, and hazards.

Further guidance on establishing systems for the safe use of moving plant including confirming the suitability of plant, systems to verify operator competencies to address unsafe operation, requirements for communication systems, plant zoning and restrictions, and specific controls for loading and unloading is included in the *Code of practice: Moving plant on construction sites*.

12.3 Standards for rollover and falling object protective structures (ROPS and FOPS)

Control measures such as rollover protective structures (ROPS) and falling object protective structures (FOPS) must be provided if there is a risk of the plant overturning or objects falling. FOPS Level 2 should be provided unless it can be demonstrated that plant will not be exposed to high-energy falling objects during operation.

Inspections should be carried out in accordance with the manufacturer's recommendations with consideration to intervals appropriate to the operating environment, with annual inspections recommended to verify ongoing structural integrity and attachment.

Where structural integrity of the ROPS or FOPS is compromised and cannot be assured e.g. damaged, modified, or subjected to significant impact, the plant must be removed from service and the control measure inspected, maintained , repaired or replaced to ensure it remains effective. PCBUs must ensure that any repairs, alterations or modifications are undertaken by competent persons.

ROPS and FOPS should comply or conform with the design standard for the relevant plant. Examples of these standards include:

- Australian Standard *AS 2294.1-1997 Series – Earth-moving Machinery – Protective Structures* (where current)
- Australian Standard *AS 2294.1-1997 – Earth-moving machinery – Protective structures – Part 1: General*
- Australian Standard *AS ISO 3471 – Earth-moving machinery — Roll-over protective structures — Laboratory tests and performance requirements*
- Australian Standard *AS ISO 3449 – Earth-moving machinery — Falling-object protective structures — Laboratory tests and performance requirements*
- Australian Standard *AS ISO 12117:2020 – Earth-moving machinery — Tip-over protection structure (TOPS) for compact excavators - Laboratory tests and performance requirements.*

12.4 Elevating work platforms (EWP)

PCBUs should refer to *Code of practice: Elevating work platforms* for further information.

In underground and tunnelling environments, additional risks associated with restricted clearances, overhead obstacles, and confined spaces must be considered in the selection and use of EWPs. Where there is a foreseeable risk of operator entrapment or crushing between the platform and tunnel linings, services, ground support, or other fixed structures, EWPs fitted with secondary crush protection or anti-entrapment systems must be selected, so far as is reasonably practicable.

12.5 Specifying plant for use underground

Equipment should be specifically designed for use in underground environments. This includes the use of fire-resistant materials, low-emission engines, and intrinsically safe components where required.

Where practicable, underground mechanical plant, including locomotives should be fitted with automatic fire suppression systems and use fire-resistant hydraulic fluids to reduce fire risk and enhance operational safety.

Table 7: Typical machine hazards and controls

Hazard category	Example control measures
Mechanical hazards	Guarding of moving parts, interlocks, emergency stop systems.
Electrical hazards	Compliance with Australian Standard *AS 4024.1 series – Safety of machinery*, insulation, grounding, lockout/tagout procedures.
Fire and explosion risks	Fire suppression systems, fire resistant and flame-retardant materials, monitoring of flammable gases (refer Chapter 12.10 Belt Conveyors in this Code).
Falling objects/ground collapse	Protective canopies, structural reinforcement, geotechnical monitoring.
Poor visibility/lighting	Installation of adequate lighting systems, reflective markings.
Hazardous atmospheres	Gas detection systems, ventilation, use of Australian/New Zealand Standard *AS/NZS 60079 series – Explosive atmospheres* for zoning of explosive atmospheres.
Noise and vibration	Noise dampening materials, vibration isolation, operator exposure limits.
Ergonomic hazards	Accessible controls, safe access and egress, operator seating and layout.
Maintenance hazards	Safe access platforms, lockout/tagout, maintenance procedures and training.
Misuse scenarios	Operator training, warning systems, design limits and fail-safes.

12.6 Blind spots

Blind spots may exist due to plant design and/or the site environment.

- As part of a risk assessment with moving plant, PCBUs should consider:
- blind spot diagrams provided in the plant manufacturer's operating manual and the availability of visual aids incorporated in the design of the plant to assist operator visibility,
- additional control measures, such as reversing cameras and proximity sensors,
- setting up the work site with view to minimising additional blind spots,
- separation and delineation systems, such as physical barriers, boom gates or similar systems,
- establishing systems so that plant operators:
  - slow down, to no more than walking speed when negotiating blind spots,
  - notify or alert others before negotiating the blind spot (for example, sound horn, radio calls, or similar),
- use of spotters as part of controlled working procedures,

- blind spots when workers on foot are approaching moving plant during operation. Before approaching moving plant, workers need to confirm through verbal communication (e.g. via a two-way radio) with the plant operator that it is safe to approach.

12.7 Pre-start & maintenance checks

Inspection and maintenance regimes should be commensurate with the underground operating environment and account for increased exposure to heat, moisture, vibration, contaminants, and corrosive conditions.

Pre-start checks should be conducted regularly and include the inspection and functionality of safety critical systems e.g. brakes, fluid levels, fluid leaks, warning devices, lighting, and emergency systems.

A preventive maintenance program should be implemented in accordance with the manufacturer's recommendations, or if not available in accordance with the recommendations of a competent person. Any defective equipment should be immediately withdrawn from service and not used until repaired by a competent person.

12.8 Fluid power systems

Hydraulic systems are integral to tunnelling machinery such as tunnel boring machines (TBMs), roadheaders, and excavators.

The fluids used in these systems pose potential risks including death, fire, environmental contamination, mechanical failure and personal injury.

Effective management of hydraulic fluids and compressed air systems is essential to ensure worker safety and should be subject to SWMS for operation and maintenance.

Further detail may be found in *Hydraulic Safety* published by NSW Department of Planning and Environment[11] and *TRG 41 Technical reference guide: Fluid power safety systems at mines* published by the NSW Resources Regulator (NSW Department of Primary Industries and Regional Development)[12].

12.9 Remote control operations

Remote-controlled plant and equipment can reduce worker exposure to high-risk environments; however, they introduce unique hazards that must be identified and managed. Serious injuries have occurred where operators of remote-controlled plant have been struck, trapped, or crushed by the plant they were operating due to unsafe operator positioning, loss of situational awareness, or inadequate system controls.

Remote operated and/or automated moving plant may be an effective control for works in hazardous environments, including around shafts, watercourses, unstable ground, demolition areas, or other identified high-risk locations.

Where remote-controlled plant is used, control measures to reduce the risk include:

- the plant and associated control systems should be fit for purpose and suitable for the intended task and operating environment,
- it should be designed to fail to safe if connectivity is lost or in the event of a malfunction,

11 Hydraulic safety Mining design guideline | MDG 3007
12 TRG 41 Technical reference guide: Fluid power safety systems at mines

- a safe operator location should be established, positioned outside the operating envelope and any foreseeable path of movement of the plant or its attachments, such that the operator cannot be struck, trapped, or overrun, and is protected from secondary hazards such as falling objects, ground instability, or traffic,
- operators should have adequate situational awareness of the operating area, achieved through direct line of sight and/or the use of cameras, sensors, spotters, or other suitable means,
- remote-control systems must incorporate readily accessible emergency stop functions,
- operators must be provided with training, instruction and supervision required for the safe use of the remote-control system,
- exclusion zones should be established and maintained around the operating area to prevent inadvertent entry by other persons,
- real-time video monitoring should be provided to manage pedestrian and plant exclusion zones to avoid collisions and monitor the effectiveness of exclusion zones where practicable,
- engineering controlled safety systems should be designed to fail to a safe state in the event of signal loss, power failure, or malfunction.

Where automated plant is used, the person with management and control of the plant must ensure that the plant does not collide with pedestrians or other powered mobile plant. Control measures should be implemented to prevent the automated plant colliding with a person or thing, and encroaching into circumstances likely to cause harm, including defined exclusion or geofenced areas, proximity to power lines, hazardous or explosive atmospheres, water inundation zones, over-capacity movements, or other similar hazards.

12.10 Transport systems for spoil and materials

General

Transport systems for spoil and materials in tunnels should be designed and operated to ensure the safety of workers and the integrity of the tunnel environment. Risks arising from these transport systems must be eliminated so far as reasonably practicable. Where risks cannot be eliminated, PCBUs must implement control measures in accordance with the hierarchy of controls, giving priority to substitution, isolation, and engineering controls and control measures must be integrated across the work occurring across the site.

PCBUs should refer to *Code of practice: Moving plant on construction sites* for further information.

Belt conveyors

Belt conveyors should be designed, installed, and operated to minimise risks to workers. Conveyors used underground should comply with Australian/New Zealand Standard *AS/NZS 4024.3611:2015 – Safety of machinery – Part 3611: Conveyors – Belt conveyors for bulk materials handling*, which sets requirements for guarding, emergency stopping, access, and control systems.

Belt conveyors should be effectively guarded to prevent entanglement, crushing, shearing, or contact with moving parts, including at nip points, rollers, drives, and transfer locations. Emergency stop pull cords or emergency stop devices should be readily accessible along the full length of the conveyor and at transfer points and must be clearly identified and tested at appropriate intervals.

Regular inspection, testing, and maintenance must be carried out by competent persons to ensure continued safe operation and to prevent mechanical failure, overheating, or fire risk. Identified defects should be rectified promptly, and damaged or unsafe conveyors must be removed from service until made safe.

Dust suppression and ventilation should be provided where the operation of belt conveyors has the potential to generate airborne contaminants, particularly at belt transfer points, loading and discharge locations, and areas where material is dropped or disturbed.

Conveyor belts used underground should be manufactured from fire rated, anti-static (FRAS) materials suitable for the operating environment and consistent with fire risk controls for underground works[13].

Slurry transport systems

Slurry transport systems are a pressured fluid power (hydraulic) system to transport slurry to and from the TBM and slurry treatment plant.

The design, installation, operation, inspection, and maintenance of slurry transport systems should be informed by Australian and New Zealand Standards, including:

- *AS 4041 – Pressure piping* – applicable to high-pressure slurry pipelines, manifolds, and associated fittings,
- *AS 1210 – Pressure vessels* – applicable to slurry tanks, pressure vessels, and components of separation plants,
- *AS/NZS 2566 – Buried flexible pipelines* – applicable to plastic slurry pipelines, including HDPE systems, where used,
- *AS 4024 series – Safety of machinery* – applicable to slurry pumps, drives, guarding, isolation, emergency stopping, and maintenance access.

Further general guidance can be found in the International Tunnelling and Underground Space Association (ITA) publications on mechanised tunnelling and slurry TBM operations, including slurry transport systems, separation plants, and intermediate pumping arrangements.

Slurry systems, including pumps, piping, valves and ancillary dosing systems, require installation, operation and regular maintenance by competent persons. Operation, inspection and maintenance must be in accordance with the original equipment manufacturers' instructions including monitoring for vibrations, leaks, excessive noise, heat and drive system operation. Effective isolation processes must be established to ensure the hydraulic system is deenergised prior to any maintenance works commencing.

Trucks

Trucks used underground should be fitted with reversing alarms and cameras and their engines fitted with fire suppression systems. They should utilise low-emission engines or exhaust treatment systems (refer Chapters 17.2 and 18 in this Code).

Designated loading and tipping areas should be established and maintained. Operators must be provided with appropriate training, instruction and information and competence should be verified.

13 Refer for example Resources Regulator's TRG 3608: Non-metallic materials for use in underground coal mines and reclaim tunnels in coal mines, EN 1366 – Fire resistance tests for service installations, AS/NZS 1530.3:1999 – methods for fire tests on building materials, components and structures – Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release & AS/NZS 1530.4:2014 – Methods of fire tests on building materials, components and structures – Part 4: Fire resistance tests for elements of construction

Railways

The use of railways underground requires safe systems of work to be developed that reflect the complexity of the railway system and its interaction with tunnelling activities. Operating procedures should be based on a systematic risk assessment and be appropriate to the nature, scale, and operating environment of the underground railway. Operating procedures should include, as a minimum:

- lighting,
- load capacity with respect to alignment, gradient, braking and traction control,
- train control procedures including required stopping distances and emergencies,
- communications and signalling controls,
- visibility aids,
- train speeds and temporary speed restrictions,
- clearances,
- pedestrian separation,
- driver containment,
- walkways and crossing points,
- interaction with other tunnelling activities,
- passing points and junctions,
- carriage of persons and/or materials,
- driver competence and authorisation,
- locomotive and rolling stock maintenance,
- track inspection and maintenance.

While construction railways used in tunnelling projects may be subject to exemptions under the Rail Safety National Law, guidance produced by Australian rail safety bodies remains relevant and should be used to inform safe system design and operation. In particular, reference should be made to guidance, standards, and codes of practice published by:

- Rail Industry Safety and Standards Board (RiSSB),
- Office of the National Rail Safety Regulator (ONRSR),
- And any relevant code of practice published by SafeWork NSW

as appropriate to the railway configuration and operational risk profile.

Further supplementary guidance may also be found in international best-practice documents, such as the Crossrail Best Practice Guide *"Construction Railways Operations"*, noting that such documents should be applied with due consideration of Australian regulatory frameworks and site-specific conditions.

12.11 Use of batteries

Overview

Whilst this Code cannot account for all possible battery applications, a systematic approach should be adopted to consider the particular hazards, circumstances of use and the latest relevant technical information.

Risks from batteries include fire and explosion, chemical exposure, electric shock or electrocution, improper storage and handling, and thermal runaway,

Control measures include:

- Risk assessment of all activities involving batteries, including consideration of:
  - the potential combustibility of the atmosphere where batteries may be used,
  - location of where equipment will be operated and charged,
  - the use and application for batteries,
  - the type of battery selected,
  - safe storage and handling requirements,
  - the characteristics of the charging circuit,
  - fire and explosion risks,
  - electric shock or electrocution risks during maintenance work,
  - the extent and frequency of maintenance and inspection requirements,
  - emergency procedures required.
- Implementing controls to prevent incompatible battery/charger combinations.
- Following original equipment manufacturers (OEM) recommendations for the battery and/or plant.
- Selecting batteries with a lower fire and explosion risk.
- Using the correct type and rating of battery for the application e.g. for some applications, a ‘deep cycling’ battery may be more appropriate.
- Ensuring regular, appropriate battery inspection and maintenance.
- Following correct charging characteristics. Do not overcharge batteries. Standby equipment e.g. fire pumps and generators, may use continuous float (trickle) charging instead of charging at a higher current.
- Before removing terminal clamps, ensure current isn’t being drawn from the battery e.g. open the battery isolator switch. Sparking at disconnection can be an ignition source.
- Safe disposal of damaged batteries.
- Implementing effective plant isolation, tagout and fault processes.
- In multiple battery sets, ensuring all units in the set are of compatible rating, type and condition. Do not mix old and new i.e. replace all batteries in the set at the same time.
- Determining if battery-charging stations need to be intrinsically safe to prevent fire or explosion.
- Establishing and maintaining a register of batteries used on site.
- Establishing a site standard on battery types and their applications.
- The PCBU providing correct PPE for use by workers when working with batteries.
- Workers using the correct PPE provided by the PCBU.

- PCBUs must ensure that information, training or instruction given to a worker is suitable and adequate, having regard to the nature of the work, risks associated with the work and the control measures implemented.
- Regular auditing to ensure conformance to the operating requirements.
- Consider the location of charging stations and proximity to flammable or combustible liquids, flammable gases or combustible dusts. If the charging station cannot be located at the surface, the location must be well ventilated and designed to prevent overheating, arcing, and other electrical faults that could lead to ignition and fires or explosions.

Lead acid batteries

Charging of lead acid batteries can produce hydrogen and oxygen that can be an explosion hazard. Lead-acid batteries have been in use underground for over a century but are limited by their lower specific energy (a ratio of their weight to energy storage) long charging times, maintenance demands and fire and explosion risks.

Lithium batteries

The adoption of lithium batteries (particularly lithium iron phosphate) to power large mobile underground plant and equipment is increasing in underground environments as they offer reduced carbon and diesel particulate emissions. Their use introduces specific health and safety risks associated with the large volume of energy stored in the batteries, requiring specific risk controls.

Lithium batteries can overheat or catch fire due to damage, overcharging, or manufacturing defects. Battery fires or malfunctions may release hazardous gases such as hydrogen fluoride, hydrogen cyanide, and volatile organic compounds and carbon monoxide. These gases can cause severe respiratory damage, skin burns, and are both toxic and combustible.

Improper storage and handling of lithium batteries can lead to physical damage resulting in short circuits, thermal runaway and fire and explosion risks, including secondary ignitions even after fires have been extinguished.

Thermal runaway can be triggered by overcharging, defects, damage, or high temperature exposure.

Emergency plans must account for battery-specific hazards and ensure safe evacuation can occur.

A PCBU at the workplace must give a copy of the emergency plan for the workplace to Fire and Rescue NSW if a total quantity of 25,000kg or more of the following kind of lithium batteries is handled or stored at a workplace—

(a) stand-alone batteries,

(b) batteries that are part of a battery pack or energy storage system,

(c) batteries that are part of an electric vehicle or item of plant that is routinely used, charged or stored at the workplace.

If Fire & Rescue NSW gives the person a written recommendation about the content or effectiveness of the emergency plan, the PCBU must revise the plan in accordance with the recommendation from Fire & Rescue NSW.

Lithium Battery Electric Vehicles (BEVs)

BEVs used underground require enhanced safety systems. Consideration should be given to the following:

- A battery thermal management system should be designed to prevent thermal runaway, a dangerous situation where a battery cell's temperature increases uncontrollably, potentially leading to fire or explosion. BEVs used underground should incorporate safe cell designs that minimize exothermic reactions. Additionally, fire-retardant materials should be included within battery modules.

- BEVs should include external fire shielding. Battery packs should be equipped with integrated fire suppression systems containing the most effective extinguishant for the battery chemistry.
- A BEV should be fitted with a high voltage interlock loop (HVIL) conforming to International Standard *ISO 17409:2020 – Electrically propelled road vehicles – Conductive power transfer*. The HVIL isa safety system that monitors and controls the high-voltage electrical system in the vehicle. An HVIL connector is another safety-critical component that is responsible for safely connecting and disconnecting the high-voltage battery system.
- High-voltage systems in BEVs present risks of electric shock, particularly during maintenance or in the event of water ingress. Manual service disconnect switches should be available for lock-out/tag-out procedures during maintenance.
- BEVs should support emergency operation modes such as 'limp home' capabilities for safe evacuation in case of partial system failure. Responding to incidents involving BEVs underground is complex.
- To protect against rock falls and mechanical impacts, BEVs should feature robust top plates and cooling systems that act as impact shields. Batteries should be securely mounted inside the vehicle frame to reduce exposure and enhance crash protection.
- Battery systems should be sealed to IP65 standards to withstand dust, moisture, and vibration. Vibration resistance should be equivalent to other machine components.

Relevant international standards for developing safe systems of working with BEVs include:

- International Standard *ISO 17409:2020 Electrically propelled road vehicles — Conductive power transfer — Safety requirements*.
- International Standard *IEC 62485-6 – Safety requirements for secondary battery installations – Part 6: Safe operation of lithium ion batteries in traction applications* / Australian Standard *AS IEC 62619: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*.
- International Standard *IEC 61000 series – Electromagnetic compatibility (EMC)*, Australian Standard *AS ISO 13766 – Earth-moving and building construction machinery - Electromagnetic compatibility (EMC) of machines with internal electrical power supply.*
- International Standard *ISO 13849-1:2023 - Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*.
- Australian Standard *AS 60529:2025 - Degrees of protection provided by enclosures (IP Code) (IEC 60529:1989(ED. 2.2) MOD)*.
- International Standard *IEC 62281 - Safety of primary and secondary lithium cells and batteries during transport* / United Nations Manual of Tests and Criteria *UN 38.3: Recommendations on the Transport of Dangerous Goods*.

13. Electrical supply and safety

WHS Act – Section 19

Primary duty of care

WHS Regulation - Part 4.7

General electrical safety in workplaces and energised electrical work

Australian/New Zealand Standard *AS/NZS 3012:2019 – Electrical installations – Construction and demolition sites*

A PCBU at a workplace must manage the risks to health and safety associated with electrical risks at the workplace. This must include risks associated with design, construction, installation, protection, maintenance and testing of electrical equipment and installations at the workplace. PCBUs should also refer to *Code of practice: Managing electrical risks in the workplace* for further information.

Consultation on the design of the electrical supply required for a tunnelling project must occur between the Client Organisation, the Principal Contractor and Designers. This consultation is required to ensure the electrical supply is fit for purpose, reliable and has built in redundancy. It is essential to ensure the electrical supply for ventilation systems are fit for purpose due to the role ventilation performs in maintaining a safe atmosphere in the tunnel.

Electrical safety should be underpinned by a risk management approach to identify all hazards involved in electrical work. In tunnelling this will involve hazards associated with:

- design requirements for electricity or power supply for the project,
- continuity and reliability of the power supply,
- the physical environment in which the equipment will operate,
- the atmosphere in which the equipment will operate,
- the work tasks associated with installation, operation, maintenance, inspection and testing,
- the nature of the works for the tunnel construction,
- fire and explosion risks including the release of toxic materials in a fire e.g. fumes from PVC-sheathed insulated cables.

Electrical work on or near energised electrical equipment is prohibited unless:

- it is necessary in the interests of health and safety that the electrical work is carried out on the equipment while the equipment is energised, (e.g. — it may be necessary that life-saving equipment remain energised and operating while electrical work is carried out on the equipment),
- it is necessary that the electrical equipment to be worked on is energised in order for the work to be carried out properly, or
- it is necessary for testing required to determine whether equipment is energised or not, or
- there is no reasonable alternative means of carrying out the work.

When working on or near energised electrical equipment, a risk assessment must be conducted and a SWMS must be prepared. PCBUs should refer to *Code of practice: Managing electrical risks in the workplace* for further information.

13.1 Continuity and reliability

As the safety of persons, effectiveness of control measures and the integrity of the works may depend on the continuity of power supply to safety-critical equipment, a reliable main electrical supply to tunnelling works is essential. PCBUs should ensure electricity supply during tunnelling operations is provided and maintained, this includes ensuring adequate backup power is available if the main electricity supply is interrupted. The duration for which any interruption of supply can be tolerated should be determined for each tunnel based on the construction method, operating conditions, and safety risks. These matters should be assessed during the planning, design and construction stages. Consultation with the relevant electrical network operator is also required.

Where necessary, and subject to risk assessment, essential standby power should be provided by a second independent mains supply, on-site generation, or other suitable arrangements. Electrical switchgear and distribution systems must be designed so that safety-critical circuits remain energised in the event of disconnection or failure of non-essential circuits. Safety critical circuits can include ventilation, lighting and communication.

Once power is supplied, control measures must be implemented to eliminate or minimise, so far as is reasonably practicable, risks associated with electrical hazards throughout the life of the works.

If mains power is lost, a competent person should assess the electrical supply system to ensure it is functioning and any faults have been identified before resuming operations.

13.2 Safety-critical equipment and hazardous atmospheres

Electrical equipment used on tunnelling sites may be exposed to high temperatures, fire, pressure, vibration, humidity, dust, hazardous substances, explosive atmospheres, and the effects of blasting. Electrical equipment selected and used must be suitable for use in hazardous or explosive atmospheres, where required.

Electrical installations and equipment should be designed, installed, and protected to prevent damage, degradation, or loss of function due to these conditions.

Safety-critical plant and equipment, including fire-fighting systems, pumps, ventilation systems, communications, and atmospheric monitoring, should be designed and installed so that they remain operational during credible power interruption scenarios.

13.3 Electrical safety management and documentation

PCBUs should establish and implement documented electrical safety management systems as a control measure. These management systems should be appropriate to the scale and complexity of the tunnelling works. As a minimum, this should include:

- an electrical safety management plan covering LV and HV installations,
- electrical design documentation and verification records,
- commissioning and energisation procedures, including defined hold points and authorisations,
- isolation, lock-out and tag-out procedures, including permit systems where applicable, and
- emergency response procedures for electrical incidents, including arc flash events.

13.4 Arc flash hazards

An arc flash is a hazardous electrical event caused by an unintended electrical arc, releasing extreme heat, pressure, and molten material. Arc flash is the light and heat produced from an arc fault - created by a short circuit between two conductors: phase to phase or phase to earth. The massive energy released in the fault can

rapidly vaporise the metal conductors and tools involved, changing it from a solid state to a gas vapour (plasma) that expands with explosive force (arc blast). The temperature of the plasma can reach 19,000°C – hotter than the surface of the sun. Exposure to the noise, concussive forces, blasted molten metal, high-energy radiation and temperatures can be catastrophic.

The radiant energy released by an electric arc is capable of permanently injuring or killing people. Arc flashes may cause severe burns to the skin and flash burns to the face and eyes. Inhaled hot gases and molten particles can cause serious internal burns to the throat and lungs. Injury can also occur through the impact from flying debris and dislodged components, or by the concussive blast.

Arc flash can occur during switching, testing, commissioning, or maintenance of electrical equipment and can cause severe injury or death to persons in the vicinity, even without direct contact with live parts.

Arc flash hazards are most commonly associated with high-voltage (HV) electrical installations and low-voltage (LV) electrical equipment, including LV switchboards, motor control centres, and distribution panels. Arc flash hazards must be identified, assessed, and controlled.

For HV electrical installations, arc flash hazards should be managed in accordance with:

- the requirements of the relevant electrical network operator and applicable HV electrical rules, including requirements for system design, protection settings, switching procedures, access controls, and authorisation of HV work, and
- recognised industry guidance for arc flash hazard management, such as the Australian Energy Council's *Electric Arc Flash Hazard Management Guideline*, including guidance on arc flash risk assessment, equipment labelling, definition of arc flash boundaries, specification of arc-rated PPE, and development of safe operating and switching procedures for HV systems.

Arc flash risk management for HV electrical installations should address:

- arc flash risk assessment for HV switchboards and equipment,
- isolation and testing procedures,
- arc flash labelling and warning signage,
- definition and management of arc flash boundaries,
- selection and use of arc-rated PPE, and
- documented procedures for normal operation, switching, commissioning, testing, maintenance, and fault response.

Arc flash risks associated with LV and ELV electrical equipment, including LV switchboards, should be managed in accordance with Australian/New Zealand Standard *AS/NZS 4836:2023 – Safe working on or near low-voltage and extra-low voltage electrical installations and equipment*, as outlined in Chapter 13.5 of this Code.

13.5 Standards compliance and competency

Electrical installations on tunnelling sites must comply with the Australian/New Zealand Standard *AS/NZS 3012:2019 – Electrical installations – Construction and demolition sites*. PCBUs should also refer to *AS/NZS 3000:2018 – Electrical installations (known as the Australian/New Zealand Wiring Rules)*, and *AS/NZS 4836:2023 - Safe working on or near low-voltage electrical installations and equipment* as applicable to low-voltage (LV) and extra-low-voltage (ELV) electrical work only.

Electrical equipment should be inspected, tested, and tagged in accordance with Australian/New Zealand Standard *AS/NZS 3760:2022 – In-service safety inspection and testing of electrical equipment and RCDs* by a competent person. PCBUs should refer to *Code of practice: Managing electrical risks in the workplace* for further information.

14. Lighting and illumination

14.1 General

Adequate lighting underground is essential to establishing and maintaining a safe workplace.

Lighting must:

- comply with Australian/New Zealand Standard *AS/NZS 3012.2019 – Electrical installations – Construction and demolition sites*, and
- allow workers and others to move, work, and evacuate safely, and enable safe entry and exit from the workplace.

Lighting levels should enable workers, mobile plant, emergency exits and obstructions on walkways, tracks, and working areas to be clearly visible. The minimum lighting levels should be 40 lux for walkways and 160 lux for general areas. Higher lighting levels may be required in some areas, e.g. tunnel faces and other active working areas.

As tunnelling progresses and work areas, layouts, and travel distances change, lighting and exit identification systems should be reviewed and adjusted to reflect the evolving underground environment. This should include:

- clear identification of evacuation routes and exits,
- illuminated EXIT signage where practicable, and
- distance or direction indicators to the nearest exit, particularly where travel distances are extended.

Where fixed lighting systems are not practicable, suitable portable lighting including hand lamps or cap lamps, should be provided. Hand lamps or cap lamps should not be used as a primary source of lighting.

Lighting systems must be regularly inspected, tested, and maintained.

The use of LED lighting should be considered in preference to other lighting types due to its lower power demand, reduced heat output, prevention of stroboscopic effects and suitability for underground environments.

PCBUs should also refer to *Code of practice: Construction Work* for further information.

14.2 Emergency lighting

Emergency lighting must be provided and maintained in areas where a loss of normal lighting could pose a risk to workers and others, including along evacuation routes, at changes in direction, at access and egress points, and at critical safety locations.

Where it is foreseeable that flammable or explosive gases could enter the tunnel, lighting and emergency lighting installations should be suitable for the hazardous area classification and protected to at least Zone 2 requirements, so that evacuation can be undertaken with lighting remaining operational in the presence of a potentially explosive atmosphere.

Emergency lighting systems should be independent of normal lighting and operate automatically upon loss of the main power supply.

14.3 Lighting levels

Lighting level at a surface is expressed in lux. In tunnels, lighting levels are influenced by the output and location of luminaires, tunnel dimensions, surface reflectivity, and atmospheric conditions such as dust, mist, or fumes.

Lighting levels should be measured and assessed in accordance with Australian/New Zealand Standard *AS/NZS 1680.1:2006 - Interior and workplace lighting*, using a suitable light meter. Measurement and assessment should be undertaken by a competent person, being a person with knowledge and experience in lighting assessment and the application of the Standard.

Monitoring of lighting levels should follow a consistent methodology, including:

- measurement at representative locations and heights relevant to the task (e.g. walkway level, working surface),
- consideration of worst-case conditions, including dust, smoke, or degraded fittings, and
- periodic reassessment as tunnel length, geometry, or work activities change.

Lighting levels should be maintained at levels that are as high as is reasonably practicable for the task and environment. The minimum lighting levels should be 40 lux for walkways and 160 lux for general areas to provide for safe movement, work, and emergency response.

14.4 Temporary lighting for maintenance and renovation

Where inspection, maintenance, renovation, or repair work is required in tunnels not fitted with permanent lighting, temporary lighting should be provided to ensure adequate illumination for the task being undertaken. Temporary lighting arrangements should be implemented in line with a risk assessment and designed, installed, and maintained to prevent electrical, mechanical, and fire hazards. Appropriate emergency provisions, including contingency lighting and safe evacuation arrangements should also be in place.

15. Lifting operations

15.1 General

PCBUs should refer to the Australian Standards *AS 2550 series: Cranes, hoists and winches – Safe use* as this provides uniform requirements and guidance for the safe use of cranes, hoists and winches.

Lifting operations can be hazardous particularly as the complexity of the lift increases. All lifting operations should be planned, controlled, and supervised by competent persons. Risk assessments should be undertaken by competent persons and effective controls must be implemented prior to commencing lifting operations. Documented procedures and lift plans are important for the planning and coordination of lifting operations and SWMS must be prepared when the work is high risk construction work.

PCBUs should establish a documented lifting management system, based on Australian Standard *AS2550 series – Cranes, hoists and winches – Safe use*, that defines classes of lifts (e.g. routine lifts, complex lifts, designed lifts, multiple crane lifts, high-risk lifts) and the level of design requirements, planning, review, and authorisation required for each class. Lift planning should be in accordance with this system.

Planning considerations include:

- selection and safe use of the crane,
- suitability of ground conditions and geotechnical reports,
- site access and crane siting,
- wind loading and weather conditions,
- lifts approaching a high proportion of the rated capacity of the lifting equipment,
- multiple-crane lifts,
- repetitive lifting operations, and
- lifting and lowering loads to significant depths below ground level, including shafts.

Lift plans should include, as a minimum, the information identified in Australian Standard *AS 2550.1-2011 - Cranes, hoists and winches – Safe use*, *Part 1: General requirements* and Australian Standard *AS 2550.5:2016 – Cranes, hoists and winches – Safe use, Part 5: Mobile cranes*, including:

- dead weight of the crane,
- lifting equipment and accessories,
- load weights, including lifting attachments,
- wind loading,
- lifting configuration and load paths,
- working radii and capacities, and
- exclusion zones and control measures.

The information contained within lift plans must be provided to lifting supervisors, plant operators, doggers and riggers, and other workers involved in the lift.

PCBUs must ensure effective control measures are implemented during multiple crane lifts. These control measures include ensuring that there are reliable methods of communicating (signalling) between the crane operator and dogger/rigger, or multiple crane operators and/or doggers/riggers. This is essential for safe crane operation. The movement of loads by lifting equipment should be, at all times, under the clear supervision and

direction of one designated controller, such as a dogger or rigger.

Where lifting operations involve designed lifts, multiple crane lifts, lifts approaching the rated capacity of the lifting equipment, or lifts of increased complexity or risk, PCBUs should consider the involvement of specialist heavy-lift expertise.

Crane selection should take into account the nature of the work, including frequent hoisting and lowering, potentially with heavy loads and extended duty cycles. Crane suppliers should be informed of the expected duty cycles to ensure the crane is suitable and not operated continuously at or near its design limits.

15.2 Lifting operations at shafts (cranes, hoists and shaft lifting systems)

This chapter applies to cranes, gantry cranes, derricks, and dedicated shaft hoists or headframe lifting systems used for lifting operations at shafts.

Where possible, the crane operator should have an uninterrupted view of the load while it is within the shaft. Where full visibility is not possible, appropriate control measures, such as visibility aids, and a safe system of work must be provided to enable the operator to safely control the load and be instructed in its movement.

To ensure safety, CCTV systems should be used where appropriate to provide visual information between the crane operator at the surface and the shaft bottom. Where CCTV is used as a control measure, clear procedures must be established to ensure any remaining risk is minimised. These administrative controls should provide for the safe handover between doggers or riggers at the shaft top and shaft bottom as the load moves in and out of camera view. CCTV should supplement, and not replace, direct supervision and visual checks by doggers or riggers.

When siting cranes near shafts, imposed ground loads should be assessed to ensure they do not adversely affect shaft stability, tunnel works, or crane stability. Crane travel paths and supporting platforms or pads should be designed and constructed:

- in accordance with any geotechnical requirements,
- in a way that ensures the stability of the crane and prevents overturning,
- to distribute crane load effectively, and
- to avoid excessive loading on tunnels or lateral pressures on shaft linings or adjacent structures.

For mobile cranes, ground bearing pressures should be ascertained and managed to remain within safe operating limits and take into account ground condition variability.

Hoisting arrangements should ensure that a minimum of three full turns of rope remain on the hoist drum when the hook is at maximum depth, including any sumps. Hoist drums should be fitted with a last-wrap protection system that prevents further lowering while allowing recovery of the load.

The weight of hoist ropes should be considered when determining safe working loads at full depth. Loads should be secured and lifted in a controlled manner to prevent uncontrolled movement, swinging, or dropping.

During lifting operations, shafts should be cleared of all non-essential personnel. Exclusion zones should be established, and essential personnel must be positioned in safe locations.

15.3 Use of winches

Only winches designed for lifting and fitted with powered-off braking systems should be used for hoisting loads. The safe working load of winches and their mountings should be clearly marked and not exceeded.

Winch mountings or anchorage points should be specifically designed, installed, and verified for the imposed loads. Inspection and maintenance systems must be implemented for winches, ropes, and associated equipment, with records retained.

15.4 Lifting with excavators

Excavators should only be used for lifting where:

- the excavator is specifically designed and rated for lifting, e.g. in accordance with Australian Standard *AS 1418.8-2008 – Cranes, hoists and winches – Part 8: Special purpose appliances*,
- lifting is limited to loads that form part of the excavation task, such as trench support, services, or excavation materials,
- the manufacturer's instructions and rated lifting charts specific to the machine and configuration are available and followed,
- the excavator is fitted with appropriate safety features, including load charts displayed in the cab, a level indicator, and load-holding or burst-protection devices where required,
- control measures are implemented to prevent loads from being suspended or travelling over any person,
- exclusion zones are established to prevent persons entering the lifting area.

Lifting of loads not associated with excavation activities should be undertaken using plant designed for crane duties, such as mobile cranes complying with Australian Standard *AS 1418.5-2013 – Cranes, hoists and winches – Part 5: Mobile cranes*.

Operator licensing and competency requirements for lifting with excavators: PCBUs should refer to Safe Work Australia's *Information sheet: Using other powered mobile plant as a crane* and High Risk Work Licensing for dogging.

16. Ventilation

16.1 Overview

Underground construction requires effective ventilation as a control measure to maintain a safe atmosphere, prevent irrespirable atmospheres from occurring and to control exposure to airborne contaminants and heat. Contaminants may include dust (including respirable crystalline silica), diesel particulate matter (DPM), engine emissions, gases generated by blasting, gases released from oxidation of organic materials, or gases desorbed from or reacting with the surrounding geology.

Underground spaces are at increased risk of hazardous atmospheric conditions because:

- excavations can be a receptacle for gases and fumes that are heavier than air,
- airborne contaminants may be generated by construction processes, e.g. engine emissions, blasting, welding, and oxy-cutting,
- gases may be introduced through leakage from gas cylinders, fuel systems, sewers, drains, gas services, or LPG installations,
- oxygen concentrations may be depleted by internal combustion engines, oxidation processes, or other natural processes,
- flammable gases, and some airborne dusts when dispersed at sufficient concentration, can be ignited or become explosive if not adequately diluted,
- dust, DPM, fumes from welding or oxy-cutting, and some gases can impair visibility and cause acute illness as well as chronic disease,
- hazardous contaminants may be generated during emergencies, including combustion of synthetic materials (e.g. PVC belting or refrigerants) producing gases such as hydrogen chloride, hydrogen cyanide, or phosgene,
- ammonia may be present due to explosives use, certain cement-based grouts, or ingress from adjacent sewerage or wastewater systems,
- granitic or uranium-bearing rocks may generate radon, a naturally occurring radioactive gas that can accumulate in low points and pose long-term health risks, and
- heat and humidity can reach hazardous levels.

These hazards may also be encountered in shafts, drives, pits, caverns, cross passages, bored or drilled pier holes, and trenches.

As the detrimental effects of inadequate ventilation can be short-term, or cumulative and long-term, mechanical ventilation systems must be effective in:

- supplying sufficient fresh air for respiration,
- diluting or removing airborne contaminants,
- controlling air temperature (e.g. heat) and humidity, and
- maintaining visibility and safe working conditions.

Ventilation is required in underground areas when workers are or are likely to be present, including periods when no active excavation is occurring, to manage residual contaminants, heat, humidity, and to maintain safe access and egress.

Ventilation system design and operation require consideration of fresh air supply, contaminant sources and generation rates, construction staging, interaction with plant and equipment, and the need for the system to be adapted as tunnelling progresses.

Ventilation systems should be designed by competent ventilation engineers. Ventilation systems must be monitored and maintained to ensure the effectiveness of the control measure. Confirmation of performance against design requirements should be regularly undertaken.

Where second-hand or refurbished ventilation equipment is proposed, the PCBU should verify its suitability, capacity, condition, certification, and maintenance history against the ventilation design requirements.

Designers and design verifiers of installation, commissioning, operation, and maintenance of any ventilation system, should have access to all relevant information to assess:

- the purposes for which the ventilation system is designed (e.g. contaminant capture, supply of fresh air, heat control),
- the results of any calculations, analysis, testing or examination,
- any operating conditions, monitoring requirements, or design validation steps necessary to ensure the ventilation system can be used without risks to health and safety for its intended purposes.

16.2 Ventilation system requirements

Ventilation systems should be designed to maintain air quality, thermal comfort, and safe working conditions while the tunnel is occupied (see also Chapter 17 of this Code) and be based on the anticipated sequence of construction.

Ventilation systems should be capable of being extended, repositioned, or modified as tunnelling progresses.

Following breakthrough, junctioning, or significant changes to tunnel geometry or activities, ventilation performance should be reassessed and adjusted as necessary.

Ventilation systems may consist of either a forced supply of fresh air to the working face, extraction of vitiated air from the tunnel, or a combination of supply and exhaust (overlap systems). Overlap systems may include filters, dust extractors, and auxiliary air movers to assist local contaminant control and reduce stagnant air zones. Where practicable, vitiated air should be extracted from the work area rather than filtered and recirculated, particularly where respirable crystalline silica (RCS) or DPM is present.

For overlap systems, the limited zone of influence of extraction ducts should be factored in. Multiple extraction points may be required to ensure effective dust capture. Extraction ducts should be positioned as close as practicable to contaminant sources. To avoid the need for workers to enter areas of unsupported ground, mechanical handling or extension of the ducting should be used where practicable.

The ventilation system should be designed and operated to achieve the following minimum criteria:

- Fresh air intakes should be located to avoid sources of contamination or recirculation.
- Portal and shaft ventilation discharges should be designed to prevent secondary exposure or risk to surrounding areas.
- Supplied fresh air should be as cool and dry as is reasonably practicable.
- The tunnel atmosphere should be considered as oxygen-deficient when the concentration of oxygen falls below 19.5%. Trigger Action and Response Plans (TARPs) should be set accordingly.
- Airflow volumes should be determined for the purposes of the Ventilation Control Plan based on the number of workers, equipment in use, contaminant generation rates, and adjusted dynamically as conditions change.
- For active excavation under conventional tunnelling operations, a minimum average air velocity of 0.5 m/s should be maintained across the tunnel cross-section in the direction of the working face in areas where workers are working or expected to work, to limit dust backflow. This velocity should be measured as a

cross-sectional average using spot or traverse surveys, at representative locations allowing for turbulence affects from operating machinery[14]. The minimum average air velocity should not be relied upon as a sole control measure, on its own as it is unlikely to achieve compliance with workplace exposure standards[15].

- In shafts, caverns, cross passages, and other confined geometries where this velocity may not be achievable, satellite fans may be used to boost localised air velocity to increase ventilation effectiveness. The effectiveness of these additional control measures should be demonstrated through alternative performance measures such as contaminant concentrations, airflow distribution, and thermal conditions.
- Air velocities should be managed to avoid unintended consequences. Sustained air velocities significantly above typical construction ventilation ranges (often in the order of 2.0 m/s) can result in secondary dust generation, drying of tunnel surfaces, disruption of dust suppression or scrubbing systems, reduced effectiveness of respiratory protective equipment, and increased turbulence.
- Air recirculation may be necessary as part of the ventilation strategy. Where recirculation is used, it should be minimised so far as is reasonably practicable, and it must be demonstrated that filtration is effective and that air quality is not degraded.
- Air velocity and contaminant concentrations should be monitored continuously or at regular intervals using calibrated instruments. Monitoring approaches may include fixed sensors, portable instruments, and periodic verification surveys.
- Ventilation airflow volumes, including additional fresh air for dilution where required, should be sufficient to maintain contaminants below workplace exposure standards, including RCS, DPM, carbon monoxide (CO), and nitrogen dioxide (NO_2), and to maintain oxygen concentrations above 19.5%.
- Where methane or other flammable gases may be present, ventilation volumes and velocities should be increased and managed to prevent the accumulation of flammable atmospheres.
- The ventilation design should account for blockage or redirection of airflow caused by plant, equipment, services, or stored materials.
- In large excavations, such as caverns additional localised ventilation may be required to achieve effective contaminant control and thermal comfort.
- Ventilation systems must be designed to accommodate emergency scenarios, to support safe evacuation.
- Continuous air quality monitoring and ventilation performance checks should be implemented, with alarms and contingency arrangements established for exceedances.

Ventilation systems should be implemented in conjunction with other dust control measures, including water suppression systems, dust extractors positioned near the excavation face, remote operation of equipment, and pressurised cabins for mobile plant operators to minimise risks in accordance with the hierarchy of control. Control measures for respirable crystalline silica and diesel particulate matter are provided in Appendix H.

Ducting and airflow regulation

Airflow should be managed using a combination of rigid and flexible ducting systems. Rigid ducting — typically steel, fibreglass or high-density polyethylene (HDPE) — is commonly used for main ventilation lines operating under negative pressure. Flexible ducting, constructed from PVC, polyethylene, or coated fabric is generally used for forced air ventilation. In hazardous, flammable, or explosive environments, ducting materials should be suitable for the operating conditions.

Airways may include shafts or ventilation raises used to supply fresh air from the surface or to exhaust vitiated air. Service drives or headings may also form part of the ventilation airflow paths.

14 For further information refer to Australian Tunnelling Society's Ventilation During Tunnel Construction Industry Considerations. Air Quality Working Group Information Package 7 of 12 - December 2018

15 Ibid S 1.2.3 Dilution of Contaminants

Airflow distribution and regulation should be achieved by adjusting fan settings, installing booster or auxiliary fans to increase flow to specific areas, and using brattice, fabric stoppings, or brattice wings to direct airflow and prevent short-circuiting.

Earthing & bonding of ventilation system components

The movement of dust and gases through ventilation systems can generate static electricity.

To prevent the accumulation of electrostatic charge and associated ignition risks, ventilation system components should be bonded and earthed, and ducting materials should be fire rated and anti-static (FRAS).[16]

16.3 Development of Ventilation Control Plans

The requirements and procedures for operating and maintaining a ventilation system should be documented in a site-specific Ventilation Control Plan. This should, at a minimum, address the following matters:

(a) the installation of ventilation control devices to manage the supply and distribution of air underground and the procedures used to prevent uncontrolled changes,

(b) the development of procedures for the construction, installation, use and maintenance of ventilation control devices,

(c) the placement of fans, and provision of devices for fan operation such as measuring or monitoring devices,

(d) the maintenance of return airways in a suitable condition so that they are accessible to those who need to inspect them or maintain them or travel through them in an emergency,

(e) certification and testing requirements for earthing and bonding of the ventilation system,

(f) the competencies of workers who design, operate, maintain, or adjust any part or the whole of the ventilation system,

(g) the processes that will ensure that only workers with the required competencies operate, maintain, or adjust any part or the whole of the ventilation system in operation,

(h) the means by which heat related illness conditions will be monitored, reviewed and controlled,

(i) reporting procedures relating to proposal and acceptance of necessary changes to the ventilation system,

(j) the maintenance and frequency of revision and update of ventilation records and control plans,

(k) ensuring that no person enters any area that is not ventilated, unless for the purposes of installing or repairing ventilation and only then subject to risk assessment and confined space control procedures,

(l) how exposure to airborne contaminants in the atmosphere operation will be controlled, including the provision of sufficient ventilation to dilute harmful dust, DPM, other airborne particulates, and exhaust emissions. This should include a specific drill and blast ventilation control plan if explosives are to be used,

(m) control procedures for starting, stopping and adjusting ventilation fans,

(n) the levels of methane and other flammable gases at which a detector will activate its alarm and the procedures to be followed when that occurs, (Trigger, Action and Response Plans or TARPs),

16 Refer for example NSW Resources Regulator TRG 3608: Non-metallic materials for use in underground coal mines and reclaim tunnels in coal mines, EN 1366 – Fire resistance tests for service installations, AS/NZS 1530.3:1999 – Methods for fire tests on building materials, components and structures, Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release and AS/NZS 1530.4:2014 - Methods of fire tests on building materials, components and structures, Part 4: Fire resistance tests for elements of construction

(o) measures to be taken to monitor and maintain TWL above 140W/m2 (refer Table 1, Chapter 5.5) and ensure air velocity is => 0.5m/s, where persons are working or are expected to work,

(p) the procedure regarding the action to be taken when monitoring identifies the presence of noxious gases,

(q) the criteria for determining that ventilation is inadequate at any underground worksite in relation to the quality, quantity, and velocity of air provided by the ventilation system such that workers can be evacuated from the affected part to an unaffected part or completely from the underground works,

(r) the procedures to be followed and the actions to be taken to ensure the safety of workers if the ventilation system fails in part or totally,

(s) the safe withdrawal of workers from the underground to a place of safety when it is necessary to withdraw them from the underground parts under fire emergency or any other circumstances, and

(t) how the management system will ensure an alarm is given in the event of failure of critical elements of the ventilation system in relation to minimum operating parameters for health or safety.

16.4 Repairs, maintenance and cleaning

WHS Regulation Section 37

Maintenance of control measures

Testing for effectiveness

The Ventilation Control Plan should define how the operation and effectiveness of ventilation systems are to be regularly tested, particularly in long tunnels. Testing should confirm that the system continues to meet operational and exposure control requirements, given changes in tunnel length, geometry, activities, or configuration since the previous assessment, and identifying any modifications required.

Repairs and maintenance

As a ventilation system is used as a control measure, PCBUs must ensure that the control measure is, and is maintained so that it remains, effective. PCBUs must undertake regular inspection and maintenance of ventilation systems with any leaks, or damage, or restrictions to airflow remedied as soon as possible. PCBUs must ensure that the maintenance, inspection and, if necessary, testing of the plant is carried out by a competent person. The maintenance, inspection and testing must be carried out in accordance with the manufacturer's recommendations, or if there are no manufacturer's recommendations — in accordance with the recommendations of a competent person.

Replacement of bag filters and dust collectors

Air filters and dust collection systems, including bag filters fitted to drills, engine air-intake filters, and particulate filters, can release accumulated dust during removal, replacement, or maintenance activities. These activities should be undertaken in a controlled area using methods that prevent the release of dust into the work environment.

PCBUs must eliminate or minimise risks arising from maintenance, cleaning and filter replacement activities. Workers involved in maintenance, cleaning and filter replacement activities must be provided with adequate information, training, instruction and appropriate PPE. Waste from these activities must be handled and disposed of in a manner that effectively controls the risk and prevents primary and secondary dust exposure or contamination of work areas.

The use of compressed air for cleaning enclosures, plant, or components during maintenance activities can stir

accumulated dust and significantly increase airborne dust concentrations. The use of compressed air for cleaning should be avoided.

Controls to eliminate or minimise dust remobilisation include preventing dust ingress through equipment design, sealing and pressurisation of enclosures, the use of vacuum or local exhaust ventilation systems (such as portable local exhaust ventilation), and other suitable low-dust or wet cleaning methods.

16.5 Alarm settings and responses

Alarms generated by atmospheric monitoring systems are used to identify hazardous conditions. When alarms are triggered, there should be clear procedures in place to support a prompt and effective response e.g. a TARP.

The TARP should define project-specific alarm thresholds and the corresponding actions required, including criteria for stopping work and evacuating or relocating personnel. These requirements should be clearly documented, understood and communicated as part of overall worksite planning, inductions and pre-start procedures.

Alarm response procedures should include, as a minimum:

- immediate communication to all affected workers,
- safe evacuation or relocation to a lower-risk area where required,
- isolation or adjustment of plant, equipment, or activities contributing to the alarm condition, where this can be done safely, and
- investigation of the cause of the alarm by competent workers.

Response protocols should be documented within the project's risk management procedures, tested through regular drills, and reinforced through training to ensure alarms are treated as a priority health and safety control measure.

Subject to pre-planned and risk-assessed protocols, a two level alarm system may be used to enable interventions or adjustment of ventilation system operation and work activities before conditions escalate to a Level 2 response. These protocols should be regularly reviewed and updated to ensure effectiveness.

In the event of a Level 2 alarm, self-rescuers should be donned where required, and evacuation carried out in accordance with the emergency plan.

Table 8: Air quality alarm settings (refer also Chapter 17)

Alarm settings and responses

Normal operation	Level 1 alarm (warning)	Level 2 alarm (evacuation)
Atmospheric conditions are within acceptable limits	A deterioration in atmospheric conditions presents a potential threat to health and safety, but conditions remain acceptable without immediate evacuation.	An unsafe atmospheric condition exists.
Maintain required resources for adequate ventilation and monitoring	Actions must be taken in accordance with the TARP to identify the cause of the alarm, assess the rate of change, and implement pre-planned control measures to prevent further deterioration. Continued work is subject to monitoring and confirmation that conditions are stable or improving.	Tunnel must be evacuated in accordance with the emergency plan, including the use of refuges and/or places of safety (refer Chapter 21). Alarms may require self-rescuers to be donned immediately.

All persons should be within range of visual and/or audible alarms protecting their work area.
Consideration should also be given to alarms for persons who may be traversing the work areas of other workers.

17. Airborne contaminants and air quality

17.1 Overview

WHS Regulation section 49
Ensuring exposure limits for substances and mixtures are not exceeded

WHS Regulation section 50
Monitoring airborne contaminant levels

WHS Regulation section 51
Managing risks to health and safety (hazardous atmospheres)

WHS Regulation section 52
Ignition sources (hazardous atmospheres)

WHS Regulation section 351
Management of risks to health and safety (hazardous chemicals)

WHS Regulation section 352
Review control measures (hazardous chemicals)

WHS Regulation section 529CE
Monitoring in relation to processing of CSS that is high risk (crystalline silica)

PCBUs must eliminate, so far as reasonably practicable, risks to health and safety from hazardous atmospheres, exposure to hazardous chemicals and airborne contaminants. Where it is not reasonably practicable to eliminate the risks, they must be minimised so far as is reasonably practicable using the hierarchy of controls. A PCBU at a workplace must ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture.

An atmosphere is a *hazardous atmosphere* if:

- the atmosphere does not have a safe oxygen level, or
- the concentration of oxygen in the atmosphere increases the fire risk, or
- the concentration of flammable gas, vapour, mist, or fumes exceeds 5 percent of the lower explosive limit for the gas, vapour, mist or fumes, or
- combustible dust is present in a quantity and form that would result in a hazardous area.

There are also many airborne contaminants in tunnelling work from numerous sources including the:

- generation of dust from breaking or cutting rock and face excavation,
- generation of dust and gases from blasting activities,
- emission of naturally occurring gases e.g. methane, hydrogen sulphide, radon,
- generation of gases (e.g. carbon monoxide, nitrogen dioxide and sulphur dioxide) and fumes or particulate matter from diesel engines and thermal processes such as welding,
- emission of gases or vapours from services or external sources e.g. fuel tanks, sewers, drains, gas pipes and LPG tanks,
- storage or use of hazardous chemicals for ancillary work e.g. water treatment chemicals,
- generation of dust, gases, or emission of vapours in any contaminated soil or water.

The hazardous nature of gases that can be present in the tunnel atmosphere must be considered. Gases that may be present can be of a toxic, flammable, explosive, radioactive or asphyxiant nature, while some may display a combination of these properties. It is important to recognise that the monitoring and control of such gases in a tunnel atmosphere can be challenging because the concentrations rarely remain constant throughout a working day. Contaminants generated in one area of the tunnel can move to other areas.

Oxygen-deficient atmospheres can be caused by gas emission, oxygen displacement or the consumption of oxygen by oxidation. Confined spaces, or areas where ventilation is inadequate, are particularly at risk of becoming hazardous due to layering of methane in the roof, or carbon dioxide in the floor. Gases that can cause asphyxiation are methane, carbon dioxide and nitrogen.

Some gases such as methane and nitrogen are not poisonous in themselves but if they occur in sufficient quantity will displace the oxygen content of the air to a hazardous level. Air consists of approximately 79% nitrogen & other gases and 21% oxygen, so ratio of nitrogen to oxygen is approximately 4:1. Therefore a 1.5% drop in oxygen results in an approximate 7.5% displacement or increase of other gases. If oxygen level drops by 1.5% to level of 19.5% (safe lowest limit), the nitrogen level will also drop by 6%. A total % drop of 7.5 % means that 75,000 parts per million (ppm) of other gas is present to cause the 1.5% decrease in oxygen levels.

Naturally occurring flammable gases include methane, hydrogen sulphide and hydrogen. Propane, Butane and Acetylene may be present as part of the construction process due to welding or steel cutting (refer Chapter 17.6 of this Code).

Carbon monoxide occurs predominantly in the exhaust of diesel engines and in fumes from shotfiring. It also results from burning and welding. Carbon monoxide is flammable under high heat but is more hazardous as a toxic gas and may be produced by incomplete combustion and decomposition of hydrocarbons. Oxides of sulphur and nitrogen (nitric oxide and nitrogen dioxide) also occur in the exhaust from diesel engines and in fumes from shotfiring.

Hydrogen sulphide is colourless and tasteless and has a powerful odour of rotten eggs at low concentrations.

Hydrogen may occur naturally within the tunnel but can also be given off by other processes e.g. during charging and discharging of lead acid batteries or when a lithium battery enters thermal runaway. Toxic gas sources also include:

(a) chlorine, hydrogen chloride, hydrogen cyanide and phosgene, which may be produced by the combustion of synthetic materials such as PVC belting or refrigerants,

(b) ammonia, which may originate from the use of explosives, and some types of cement-based grouts, and from sewer systems, where it may accumulate or emanate into the tunnel environment,

(c) radon, a radioactive, naturally occurring gas that can be desorbed from granitic rocks through groundwater movements. As it is heavier than air, radon may collect in sumps. Due to its radioactive properties, including the release of ionising radiation, it can cause long term health effects following exposure.

Refer to Safe Work Australia's *Workplace Exposure Standards for Airborne Contaminants* and *Hazardous Chemical Information System (HCIS)* for further information.

PCBUs should carry out a risk assessment prior to the start of tunnelling work or using hazardous chemicals. Hazardous chemicals and those that are generated by construction work can be identified by referring to contaminated land assessments, geotechnical reports, product labels and safety data sheets. The risk assessment should identify the type and level of airborne contaminants and hazardous chemicals that workers may be exposed to during various stages of construction. The risk assessment should consider the acute and chronic health effects of exposure, all routes of exposure (inhalation, skin absorption, ingestion) and effects from direct skin or eye contact. PCBUs should involve competent persons in the risk assessment. This may include an Occupational Hygienist and ventilation engineers.

The risk assessment can be used to inform the following:

- the necessary control measures,
- health monitoring requirements,
- air monitoring requirements,
- the level of respiratory protection, if required.

17.2 Use of combustion engines (diesel plant)

Engines that use volatile fuels, such as petrol, should not be used underground under any circumstances. Only compressionignition engines operating on standard automotive 'low-volatility' fuel such as diesel should be permitted.

So far as is reasonably practicable, diesel exhaust emissions (DEE)should be eliminated or minimised to reduce exposure to contaminants including nitric oxide, nitrogen dioxide, carbon monoxide, sulfur oxides and fine particles known as diesel particulate matter (DPM). As exhaust emissions are a source of health risk, the use of electrically powered plant and equipment should be considered and risk assessed as part of construction method development prior to finalising ventilation system design.

Where combustion engines are necessary, diesel engines should be a minimum of Tier 4 Final or EU Stage V compliant (or equivalent) and should be maintained in optimum service condition to minimise emissions. Engines should be operated using ultra-low sulphur and other low-emission diesel fuels, fuel additives and low sulphur lubricants where possible. Care must be taken to ensure the fuel and lubricating oils are high quality and uncontaminated. All diesel fuel must comply with the *Fuel Quality Standards Act 2000*.

To control exposure to DEE in the ventilation system design, it is necessary for the Designer to consider actual emissions, number and type of machines and operating patterns. Ventilation system requirements will depend on:

- the number and power rating of machines and plant used,
- worksite arrangements, working conditions, durations and machine work rates, and
- the mechanical condition and emissions from the machines.

Where diesel-powered equipment is used, real-time monitoring of exhaust emissions, including DPM, carbon monoxide, nitrogen oxides and ammonia should be considered and integrated into the ventilation control and TARP framework, having regard to the nature of the works, plant mix, exposure risks and monitoring reliability.

17.3 Drill and blast operations

When explosives are used, ventilation arrangements should be designed and operated to effectively remove blasting fumes, dust, and gases before personnel re-enter the tunnel.

Ventilation following blasting should be based on a risk assessment that considers tunnel length, geometry, ventilation configuration, explosive type and quantity, and the potential for residual contaminants. Where practicable, ventilation strategies should prioritise the removal of vitiated air from the blast area, rather than reliance on dilution alone.

The timing of blasting activities should, so far as reasonably practicable, be planned to allow dispersion and clearance of blasting fumes and dust during periods when the tunnel is unoccupied and no workers or persons are present.

Before re-entry following blasting, the atmosphere must be assessed to confirm it is safe. As a minimum, post-blast atmospheric monitoring should address:

- carbon monoxide (CO), and
- nitrogen oxides (NO and NO_2),
- ammonia (NH_3), and
- any other contaminants identified through risk assessment.

In drill and blast tunnels utilising extraction ventilation, the first length of rigid ducting adjacent to the face is subject to frequent damage and should be treated as sacrificial, with inspection and replacement undertaken as necessary to maintain ventilation effectiveness.

To ensure the effectiveness of the ventilation system as a control measure, ventilation performance following blasting must be verified through monitoring and should be recorded in accordance with the Ventilation Control Plan. Re-entry must not occur until contaminant concentrations are below applicable workplace exposure standards and oxygen levels are confirmed to be safe.

17.4 Methane and other flammable gases

Flammable gases that may be encountered underground, include methane, ethane, propane, hydrogen sulphide, hydrogen, and carbon monoxide.

Where a foreseeable risk of methane or other flammable gases has been identified through geological assessment, historical data, or monitoring, the ventilation system and associated plant should be designed and operated to prevent the accumulation of flammable atmospheres.

As part of the risk assessment the ventilation system should be zoned in accordance with the Australian/New Zealand Standard *AS/NZS 60079 series – Explosive atmospheres* considering the likelihood, frequency, and duration of the presence of flammable gases.

Ventilation systems should remain operable at gas concentrations up to 25% of the lower explosive limit (LEL) within ventilation ducting. At this concentration, all tunnelling activities should cease, and all personnel should be withdrawn in accordance with the emergency plan.

Where monitoring indicates that flammable gas concentrations may approach levels requiring zoning beyond non-hazardous classification, additional controls should be considered, including:

- enhanced ventilation and gas dilution measures,
- fixed or portable gas detection and alarm systems,
- ignition source control measures consistent with the assigned hazardous area classification.

The selection of electrical equipment, diesel plant, battery-powered equipment, and ancillary devices should be consistent with the assessed hazardous area classification. Where required, this may include ignition-protected or suitably rated equipment.

Where methane or other flammable gases are present, ventilation airflow should be sufficient to promote effective mixing and dilution and to prevent stratification. In such circumstances, higher air velocities may be required to prevent gas layering, particularly near the roof or in low-velocity zones.

17.5 Cooling through ventilation

Ventilation airflow should be provided and managed to maintain Thermal Work Limit (TWL) values within acceptable risk categories for the work being undertaken, in accordance with Table 1.

Where TWL values approach or fall below 140 W/m^2, additional controls should be implemented, including increased airflow, work–rest regimes, redeployment of workers, or withdrawal from the affected area, consistent with the applicable TWL risk category.

17.6 Welding fumes and gases

PCBUs should refer to *Code of practice: Welding processes* and *Code of practice: Managing risks of hazardous chemicals in the workplace* for further information.

Welding, thermal cutting, and allied hot work activities generate fumes and gases that present a significant health risk in underground environments. Tunnel geometries and restricted airflow often prevent adequate dilution of welding fumes to levels below workplace exposure standards, even where general ventilation is operating effectively.

Where reasonably practicable, welding and other hot works should be undertaken at the surface.

Where welding or thermal cutting is to be performed underground, PCBUs must implement controls to eliminate or minimise exposure to welding fumes and gases so far as is reasonably practicable and ensure compliance with applicable workplace exposure standards. These controls should include, as a minimum:

- at-source fume extraction, such as on-gun extraction or integrated extraction systems, wherever practicable, or
- local or task-specific extraction ventilation positioned to capture fumes at or as close as practicable to the point of generation, where on-gun extraction is not practicable.

General tunnel ventilation should not be relied upon as the sole control measure for welding fumes.

Where substitution, isolation, engineering and administrative controls in combination cannot adequately control exposure, appropriate PPE such as Respiratory Protective Equipment (RPE) must be provided and used in accordance with a documented respiratory protection program. For welding underground, this will typically include:

- powered air-purifying respirators (PAPR), and
- filters appropriate to the hazard, such as P2 or P3 particulate filters and, where relevant, organic vapour cartridges.

The selection of RPE must be based on the nature of the welding process, consumables used, and the contaminants generated.

The hazards and risks associated with the use and storage of fuel gases commonly used for welding and cutting, including propane, butane, and acetylene, must be carefully controlled. These gases can form flammable or explosive mixtures, and propane and butane are heavier than air and may accumulate in low points such as sumps, drains, and confined spaces. Cylinders and associated equipment should be secured, protected from damage, and managed to prevent leaks.

Welding and hot work activities underground should be subject to a hot work permit system, integrated with ventilation controls, atmospheric monitoring, and emergency response arrangements.

17.7 Chemical reactions

Chemical reactions associated with tunnelling activities may generate toxic, flammable, or otherwise harmful gases and vapours. These reactions may arise from the use of construction materials (such as grouts, resins, foams, or explosives), interaction between these materials and the ground or groundwater, or changes to geochemical conditions during excavation.

PCBUs must identify hazards arising from potential chemical reactions and eliminate or minimise the risks so far as is reasonably practicable. Designers must carry out, or arrange the carrying out of, any calculations, analysis, testing or examination that may be necessary. As there are concurrent duty holders, each person with the duty must, so far as is reasonably practicable, consult, co-operate and co-ordinate activities with all other persons who have a duty in relation to the same matter. Hazard identification should be informed by:

- geotechnical and hydrogeological investigations,
- contaminated land assessments,
- groundwater chemistry data, and
- information provided by suppliers of explosives, grouts, and other chemical products, including Safety Data Sheets (SDS).

Reactive ground conditions, including the presence of sulphides or other chemically active minerals, should be specifically considered. Where chemical reactions are a foreseeable hazard, PCBUs must implement control measures to eliminate or minimise risks so far as is reasonably practicable. These control measures may include:

- selection of alternative materials with lower reactive potential,
- modification of construction methods or sequencing,
- enhanced ventilation and targeted extraction at the source of emissions,
- atmospheric monitoring for relevant reaction products, and
- restrictions on access to affected areas until safe conditions are verified.

The potential for chemical reactions and associated emissions should be reviewed throughout construction, particularly where ground conditions, materials, or methods change. Findings should be recorded and documented and reflected in the Ventilation Control Plan, risk assessments, and emergency response procedures.

17.8 Air quality monitoring

Overview

A PCBU at a workplace must ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture.

A PCBU must carry out air monitoring to determine the airborne concentration of a substance or mixture at the workplace to which a workplace exposure standard applies if:

- the PCBU is not certain on reasonable grounds whether the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure standard, or
- monitoring is necessary to determine whether there is a risk to health.

Air monitoring provides data on the concentration of airborne contaminants in workplace air and is a critical component of managing health and safety risks in tunnelling. Air monitoring is required to verify the effectiveness of control measures, identify changing conditions, and confirm compliance with workplace exposure standards. Air monitoring is undertaken to assess worker exposure and the effectiveness of control measures and does not replace or remove any requirement for health monitoring where required under the WHS Regulation.

Air monitoring data must be stored for the duration of the contract and retained for a minimum of 30 years, in accordance with section 50(2) of the WHS Regulation. Air monitoring results must be readily accessible to persons at the workplace who may be exposed to a substance or mixture in accordance with section 50(3) of the WHS Regulation.

Where the airborne concentration of respirable crystalline silica (RCS) has exceeded the workplace exposure standard, the PCBU must provide air monitoring results to SafeWork NSW, in a form approved by SafeWork NSW, as soon as reasonably practicable and no more than 14 days from the date that the air monitoring result was reported to the PCBU, in accordance with the WHS Regulation.

A tunnel under construction should have an air monitoring program that is based on a risk assessment and reflects the dynamic nature of tunnelling activities, including changes in work locations, tasks, plant, ventilation arrangements, and geological conditions.

The air monitoring program should be representative of:

- the number of workers potentially exposed,
- shifts worked and hours of exposure,
- tasks and activities undertaken, and
- environmental and operational conditions at the workplace.

Air monitoring programs should be established in accordance with recognised methodologies, such as European Standard *EN689:2019+AC:2019 Workplace exposure – Measurement of exposure by inhalation to chemical agents – Strategy for testing compliance with occupational exposure limit values*, or other statistically valid methods consistent with accepted occupational hygiene practice, including guidance published by the Australian Institute of Occupational Hygienists (AIOH).

Air monitoring should be conducted using sampling equipment that is fit for purpose and maintained to achieve the objectives of the relevant sampling methodology (e.g. applicable Australian Standards). Samples should be analysed by a laboratory accredited by the National Association of Testing Authorities (NATA).

Monitoring results should be used to inform the ongoing review of risk assessments and control measures. Where monitoring indicates elevated or increasing exposures, controls must be reviewed, validated, and adjusted as necessary. Given the variable and non-steady nature of tunnel atmospheres, continuous or real-time monitoring systems may be used to complement personal exposure monitoring and to assist in identifying trends and rapid changes in atmospheric conditions.

For further information, refer to Safe Work Australia's *Workplace Exposure Standards for Airborne Contaminants* and the *Hazardous Chemical Information System (HCIS)*.

Personal air monitoring

Tunnel construction is a dynamic environment where work tasks, locations, plant, ventilation arrangements, and exposure conditions may change frequently. The frequency and scope of personal air monitoring should reflect this variability and be determined through a documented risk assessment as part of the project's health risk management processes.

Personal air monitoring programs should be developed by a competent person such as an Occupational Hygienist, using Similar Exposure Groups (SEGs) established on the basis of observed work activities, exposure risk estimates, physical location, plant and equipment used, and the duration and frequency of exposure.

The repeat frequency of personal air monitoring for each SEG during tunnel construction should be determined through a risk-based assessment that considers:

- the likelihood and potential consequences of exposure,
- the variability of tasks, locations, and conditions,
- the effectiveness and reliability of existing control measures, and
- the potential for changes in exposure over time.

Personal air monitoring involves measuring the concentration of airborne contaminants within a worker's breathing zone during normal work activities, including routine breaks. Figure 2 illustrates an approximation of the worker's breathing zone.

Sampling equipment should be fit for purpose and used in accordance with the applicable sampling methodology. Samples that do not meet minimum requirements for sampling duration, flow rate, positioning, or quality are void or invalid and should not be used for estimating personal exposure. Sampling programs should include procedures for identifying void or invalid samples and determining, using professional judgement, whether additional sampling is required to ensure the exposure assessment remains representative.

Personal air monitoring should be undertaken by a person who has acquired the knowledge and skills to carry out the task through training, qualification, or experience. An example of the allocation of responsibilities for planning, conducting, and interpreting air monitoring is outlined in Table 9.

Figure 2 – Sampling in workers breathing zone

Table 9: Example air quality tasks

Task	Who is qualified to do air monitoring
Conduct air monitoring at the workplace (including establishing similar exposure groups and develop a sampling plan)	Occupational Hygienist
Conduct personal exposure monitoring at the workplace	Occupational Hygienist Occupational hygiene technician[17]
Interpreting the results of air monitoring, and drawing conclusions	Occupational Hygienist

To ensure that no person is exposed to an airborne concentration exceeding the exposure standard, PCBUs should ascertain that the exposure of individual workers or groups of workers does not exceed the workplace exposure standard.

17 A person with relevant qualifications and experience under the supervision of an Occupational Hygienist

Where it has been determined that RPE is required to further minimise the risk of exposure to airborne contaminants, the protection afforded by the RPE may be taken into account when assessing compliance with a workplace exposure standard, provided that:

- all other reasonably practicable higher order controls in the hierarchy of control measures have been implemented, and
- There is documented evidence that:
  - the RPE was worn correctly,
  - the RPE was worn during the period of exposure,
  - where the RPE was tight-fitting, the worker was fit-tested and clean shaven for the make and model of RPE used,
  - the protection factor of the RPE was sufficient to control the exposure, and
  - a documented respiratory protection program was in place and implemented.

The person conducting the personal air monitoring should provide monitoring results and technical interpretation of those results. Any recommendations for changes to control measures must be developed in consultation with the relevant PCBUs and workers and HSRs.

PCBUs must ensure that the results of air monitoring are readily accessible to workers and should ensure the results of personal air monitoring are communicated to affected workers. Where monitoring has been undertaken to determine compliance with a workplace exposure standard or to assess health risk, records must be retained for 30 years in accordance with section 50(2) of the WHS Regulation. Where monitoring identifies exposures above the workplace exposure standard, control measures must be reviewed and revised as necessary.

Where workers have a working day longer than eight hours or work more than 40 hours a week, the PCBU must determine whether the TWA exposure standard should be adjusted to compensate for the greater exposure during the longer work shift, and decreased recovery time between shifts.

For practical information about specific groups of substances, complying with exposure standards and adjusting exposure standards for extended work shifts, see Safe Work Australia's *Guidance on the interpretation of workplace exposure standards for airborne contaminants.*

Workers in tunnelling may be exposed to multiple airborne contaminants simultaneously, including dusts, DPM, welding fumes, and gases. These combined exposures may have additive or synergistic health effects. Risk assessments and control programs must therefore consider combined exposures and ensure that control measures are implemented and maintained to protect worker health and safety under realistic operating conditions.

For a list of exposure standards, see Safe Work Australia's *Workplace exposure standards for airborne contaminants*. From 1 December 2026, Australia will adopt the Workplace Exposure Limits (WEL) list, replacing the WES list.

Other monitoring types

In addition to personal exposure monitoring, other forms of air quality monitoring may be required to ensure the effectiveness of risk assessments, ventilation management, and control measures. These monitoring methods provide valuable operational information but do not replace personal air monitoring for the purpose of assessing compliance with workplace exposure standards. Refer also Chapter 19 for RCS.

Static (area) air monitoring

Static or fixed-position monitoring may be used to measure concentrations of dust, DPM, or gases at specific locations within the tunnel. This monitoring can assist in:

- identifying sources and patterns of contaminant generation,
- assessing the effectiveness of control measures, including ventilation,
- informing the placement of exclusion zones, and
- supporting investigation of incidents or abnormal conditions.

Results from static monitoring should not be compared directly to workplace exposure standards, as they do not represent individual worker exposure.

Stationary and portable real-time monitoring

Continuous atmospheric monitoring should be undertaken for oxygen concentration along with monitoring for the presence and concentration of all foreseeable atmospheric contaminants such as gases and particulates. Monitoring instruments should be located to take into account the buoyancy of gases as shown in Appendix C.

Static monitoring systems should have multi-level alarm and data logging capability, connected to the tunnel data and communications network. Monitoring stations should normally incorporate an audible alarm. Portable monitoring instruments should be used to supplement the fixed monitoring network.

For TBM tunnelling, there should be monitoring stations on the TBM. Additional monitoring stations should be provided as necessary. Real time concentrations should be displayed locally at the monitoring station, to machine operators at the access control point to the tunnels and in the site offices.

Portable real-time sampling uses a direct reading device to measure dusts, gases or DPM and can be used in conjunction with gravimetric sampling to detect changes in instantaneous concentrations and assessment of the source of dust exposure, the effectiveness of control measures and positioning of workers.

PCBUs should use real time portable monitoring to monitor dust levels to detect failures in control measures or changing conditions which allow for a more rapid response e.g. an increase in ventilation airflow. Personal direct reading instruments such as respirable dust monitors and multigas detectors may also be necessary due to the changing work environment.

Continuous atmospheric monitoring should be undertaken for oxygen concentration along with monitoring for the presence and concentration of all airborne contaminants that may create a hazardous atmosphere. Monitoring should be undertaken in real-time. The system should have multi-level alarm and data logging capability. Monitoring stations should be connected to the tunnel data and communications network and incorporate an audible alarm.

In mechanised tunnelling, there should be monitoring stations on the TBM whilst in conventional tunnelling there should be a monitoring station close to the face. Additional monitoring stations should be provided in all tunnels as necessary. Real time concentrations should be displayed locally at the monitoring station, to the TBM operator, at the access control point to the tunnels and in the site offices.

After blasting, monitoring must be carried out before workers re-enter the tunnel. The tunnel should be monitored for respirable dust, carbon monoxide, carbon dioxide and nitrogen oxides.

17.9 Exceedances

Where personal air monitoring results indicate that a workplace exposure standard has been exceeded, the PCBU must review and, where necessary, revise control measures to eliminate or minimise exposure so far as is reasonably practicable. Control measures must be checked to confirm they are appropriate, properly implemented, maintained, operating as intended, effective, and monitored on an ongoing basis.

Air monitoring reports should clearly document:

- the airborne contaminants monitored,
- the exposure results for the relevant worker(s) or similar exposure group(s),
- whether any applicable workplace exposure standard has been exceeded,
- the work activities, conditions, and controls in place at the time of monitoring, and
- any identified factors contributing to elevated exposures.

Where exceedances are identified, the PCBU should ensure that the source(s) of exposure are investigated and that the effectiveness of existing control measures is assessed by an Occupational Hygienist as part of the broader consultation and review requirements. The findings of this assessment should inform the development of an action plan to improve exposure control measures. This plan should be developed and implemented by the PCBU in consultation with relevant duty holders, workers, HSRs and, where appropriate, ventilation engineers.

Over-exposures to airborne contaminants, including exposures above applicable workplace exposure standards, should be treated as health and safety incidents and managed in accordance with the project's incident reporting and investigation procedures. This includes undertaking root cause analysis and implementing additional or revised control measures to prevent recurrence. Depending on the circumstances, this may also comprise a 'dangerous incident' for the purposes of the incident notification provisions (section 37 of the WHS Act).

PCBUs should ensure that air monitoring results are communicated to affected workers in a timely and understandable manner and that records are retained in accordance with legislative requirements.

18. Diesel plant – emissions management

18.1 Diesel Engine Emissions (DEE)

DEE are a complex mixture of gases, vapours, liquid aerosols and particulates produced through combustion.

The composition of DEE varies depending on:

- the type of engine,
- its age and condition,
- operating conditions (e.g. temperature, pressure, engine speed),
- emission control systems, and
- the composition of the fuel, lubricating oils and additives used.

The main chemical components of DEE are gases and vapours commonly found in air, like nitrogen, oxygen, carbon dioxide and water vapour. A small percentage of DEE is made up of hazardous chemicals like carbon monoxide, nitric oxide, nitrogen dioxide, sulfur oxides and fine particles known as diesel particulate matter (DPM).

Traces of other airborne contaminants may be present in DEE, including hydrocarbons like acrolein, formaldehyde, acetaldehyde, benzene, 1,3-butadiene, chlorobenzene, ethyl benzene, phenol, styrene, toluene, xylenes, and polycyclic aromatic hydrocarbons (PAHs).

In underground construction, DEE can present a significant health and safety risk due to the confined nature of the work environment and the potential for both short-term (acute) and long-term (chronic) effects from exposure.

Short-term effects

Short-term exposure to high concentrations of DEE can have health effects ranging from irritation of the eyes, nose, throat and lungs, light-headedness, nausea, coughing and other respiratory symptoms to asphyxiation from carbon monoxide poisoning.

Long-term-effects

DEE are carcinogenic, which means exposure can cause lung cancer and present an increased risk of bladder cancer. In addition to all DEE being considered carcinogenic, PAHs, a trace contaminant in DEE, have also been determined to be carcinogenic. Each year, around 130 Australians are diagnosed with lung cancer caused by work-related exposure to DEE. Long-term exposure can worsen asthma and allergies and increase the risk of heart and lung disease. Effective emissions management is therefore a critical component of controlling airborne contaminants underground, in conjunction with ventilation, monitoring, and occupational hygiene measures described elsewhere in this Code.

Diesel Particulate Matter (DPM)

DPM makes up only a small fraction of the total DEE. DPM is made up mostly of soot (elemental carbon), along with ultra-fine droplets of unburned hydrocarbons (from the lubricating oil or fuel additives), water mists, sulfates and trace concentrations of other particulate airborne contaminants from oil or fuel additives, some of which are hazardous.

These trace contaminants can include metals or metal compounds like arsenic, beryllium, cadmium, cobalt, inorganic lead, manganese, mercury, chromium or nickel.

More than 90% of DPM are smaller than 1 micrometre (μm). These small particles can absorb hazardous gases and vapours from the DEE onto their surfaces. Because of its small size, DPM can stay airborne for long periods

of time and can penetrate deep into the lungs, carrying other hazardous chemical components of the DEE. DEE and DPM are classified by the International Agency for Research on Cancer (IARC) as a Group 1 carcinogen (carcinogenic to humans). DPM is classified as hazardous chemicals under the WHS Regulation and must be managed to prevent exposure above prescribed exposure standards and limits. Examples of DPM control measures are provided in Appendix H.

Incidental exposure to DEE

Incidental exposure refers to situations where DEE are present in the workplace, but the source is not under the direct control of the workplace. Regardless of the source, exposure to workers and others at the workplace still needs to be minimised.

Workers at risk of incidental exposure may include those who spend a significant amount of time around diesel-powered plant and machinery, trucks loading/unloading, railway lines and roadways, traffic controllers and material handling operators.

This chapter applies to all diesel-powered plant used underground, including mobile plant, light vehicles, portable generators and other ancillary equipment.

18.2 Engine selection and baseline testing

PCBUs should implement a maintenance strategy that includes establishing a baseline for all diesel engines that will be used underground. A baseline test is an in-vehicle test of a diesel engine system when an engine is in an 'as new' or 'good operating condition'. This may occur at the introduction to site or may be part of any engine overhaul. The purpose of the test is to establish the nominal engine operating parameters and normal emissions for each engine, taking into consideration the vehicle and its transmission. The test may then be used as a benchmark for deterioration in the emission performance of an engine from the baseline.

PCBUs manufacturing or supplying diesel vehicles/plant should provide information on baseline testing, including results for:

- engine at full-load, idle and hi-idle operating condition,
- oxides of nitrogen, carbon monoxide, carbon dioxide and DPM,
- engine speed, inlet, exhaust, and boost pressures,
- engine exhaust flow rate, where practicable,
- raw exhaust and tailpipe emissions.

Important Safety Notice — Full-load Engine Testing

When conducting fullload engine testing that requires the drivetrain to be engaged, the vehicle is to be securely restrained to prevent unintended movement. Ensure appropriate wheel chocks or mechanical restraints are installed, and service brakes are fully applied prior to and throughout the test.

Failure to adequately restrain the vehicle may result in uncontrolled movement ("jumping" or runaway) while the diesel engine is under throttle, creating a serious safety hazard.

Fullload tests are typically performed as torqueconverter stall tests or hydraulic stall tests and are limited to a duration of approximately 20 seconds, unless otherwise specified by the engine or equipment manufacturer.

This test method is not applicable to engines fitted with a manual clutch configuration.

The maintenance strategy should contain the corrective actions required when unacceptable deviations from the baseline occur based on the manufacturer's recommendations or the suppliers baseline. All records and test results should be kept in a central emissions database.

18.3 Fuel quality, handling and re-fuelling

Only high-quality, uncontaminated low-sulphur diesel (<10 ppm sulphur) should be used. Fuel storage and transfer systems should prevent contamination from water or particulates.

Wherever practicable re-fuelling should be done above ground. If this is not practicable the handling of diesel fuel in the tunnel should be at locations where spillages can be contained and where ventilation is provided as diesel vapours present both toxic and fire and explosion hazards. Such locations should form part of any zoning assessment under Australian/New Zealand Standard *AS/NZS 60079 series – Explosive atmospheres*.

Where refuelling is undertaken underground, refuelling locations and practices should be designed to effectively control diesel vapours at or near their point of generation and prevent accumulation in workers' breathing zones, including through ventilation or other engineering controls.

PCBUs must establish controls to ensure safety, including workers trained and competent in safe work procedures, spill containment, and emergency procedures, including the use of fire suppression systems and extinguishing equipment.

Some items of plant require cool down periods before refuelling and such plant should be readily identified and systems of work should include suitable cool down times that are established after considering the type of plant, its running temperature, length of operation before cooling down, and the ambient temperature's effect on cool down times.

18.4 Emissions control technologies

Tier 4 Final or EU Stage V (or equivalent) compliant diesel engines are generally equipped with advanced exhaust aftertreatment systems designed to minimise harmful emissions. These systems may include Diesel Particulate Filters (DPFs), catalytic converters, Diesel Oxidation Catalysts (DOCs), and Selective Catalytic Reduction (SCR) systems.

All exhaust treatment systems fitted to engines must be properly maintained and regularly inspected in accordance with the manufacturer's requirements to ensure their continued effectiveness and safe operation.

18.5 Portable generators

The use of portable diesel generators underground should be minimised wherever possible, as they contribute to both airborne contaminants such as diesel exhaust and increased heat load in the working environment.

Where electrical power supply is required, preference should be given to using fixed electrical systems or alternative energy sources that do not generate exhaust emissions. If portable diesel generators are used, they should be fitted with effective emission controls, located in well-ventilated areas, and operated in a way that minimises worker exposure to exhaust gases and particulates and be subject to the site specific Ventilation Control Plan to ensure that appropriate airflow and extraction systems are in place to manage emissions and protect worker health.

18.6 Operating control measures

PCBUs should establish processes to ensure workers are required to minimize idling, avoid unnecessary acceleration, implement engine shut-off policies during idle periods and report any faults with the plant or engine performance issues.

PCBUs should establish processes to ensure workers visually inspect the plant to determine faults or damage and during operation to see if blue, black or white smoke is being emitted:

- Blue smoke (mainly oil and unburnt fuel) is caused by partly burnt fuel from badly worn engines which are poorly serviced or tuned.
- Black smoke (soot, oil and unburnt fuel) is produced if there is a mechanical fault with the engine or if the engine is working near its maximum speed.
- White smoke (water droplets and unburnt fuel) is produced when the engine is started from cold and disappears as the engine warms up.

18.7 Maintenance and monitoring

The person with management or control of plant at a workplace must ensure that the maintenance, inspection and, if necessary, testing of the plant is carried out by a competent person. The maintenance, inspection and testing must be carried out:

(a) in accordance with the manufacturer's recommendations, or

(b) if there are no manufacturer's recommendations — in accordance with the recommendations of a competent person, or

- in relation to inspection, if it is not reasonably practicable to comply with (a) or (b) — annually.

PCBUs should develop a preventive maintenance schedule that includes consideration of baseline data, monitoring emissions regularly and taking corrective action when deviations occur, and keep detailed records for compliance and performance tracking.

Monitoring DEE should occur at the manifold prior to any emission control measures and then at the tail pipe. Tail pipe exhaust emissions from a diesel engine should never exceed 1100 ppm of carbon monoxide or 750 ppm of oxides of nitrogen, at either load, high idle or idle. If emissions exceed these values, then the engine should be placed out of service for maintenance or repair at the earliest opportunity.

19. Respirable crystalline silica (RCS) dust

19.1 Overview

This chapter should be read in conjunction with the *Code of practice: Managing risks of respirable crystalline silica in the workplace*.

Dust, and in particular RCS dust, is a significant health hazard for workers in NSW. A person is exposed to RCS whenever the RCS is airborne and the person can breathe it in. Airborne RCS particles can be breathed deep into the lungs and cause a range of respiratory diseases, some of which are fatal.

The WHS Regulation defines a Crystalline Silica Substance (CSS) as a material containing at least 1% crystalline silica (by weight). This definition includes almost all natural ground found in NSW, as well as all concrete and other cementitious products.

The WHS Regulation defines high risk, in relation to the processing of a CSS, as the processing of a CSS that is reasonably likely to result in a risk to the health of a person at the workplace. Section 529A of the WHS Regulation also defines processing in relation to a CSS as:

- the use of power tools or mechanical plant to carry out an activity involving the crushing, cutting, grinding, trimming, sanding, abrasive polishing or drilling of a CSS,
- the use of roadheaders involving material that is a CSS,
- the quarrying of a material that is a CSS,
- mechanical screening involving material that is a CSS,
- tunnelling through a material that is a CSS, or
- a process that exposes, or is reasonably likely to expose, a person to RCS during manufacture or handling of a CSS (for example cleaning and maintenance processes such as sweeping that may disturb settled RCS).

There are many sources of RCS in tunnelling such as when:

- rock or concrete is broken, drilled, cut or blasted or wherever ground is disturbed,
- rock cutting with roadheaders or TBMs,
- loading broken rock at the face,
- transporting spoil on conveyor belts,
- working at spoil transfer points,
- installing or removing ventilation ducts,
- concreting and shotcreting, spraying and handling bagged ingredients,
- moving plant,
- loading out spoil.

A PCBU carrying out the processing of a CSS that is high risk must, before the processing commences, ensure that a silica risk control plan for the processing is prepared, or ensure that it has been prepared by another person.

The silica risk control plan must:

(a) identify all the processing of a CSS carried out at the workplace that is high risk, and

(b) include the risk assessment undertaken under section 529CA for all processing of a CSS that is high risk, and

(c) document what control measures will be used to control the risks associated with the processing that is high risk and how the measures will be implemented, monitored and reviewed, and

(d) be set out and expressed in a way that is readily accessible and understandable to persons who use it.

This information may be incorporated into the Occupational Health and Hygiene Plan.

PCBUs should assess, monitor and control exposure to RCS using the following steps as outlined in the Occupational Hygiene Management Plan (refer Chapter 5):

- potential sources of RCS generation should be identified in all areas of the construction site, during demolition, construction and fit-out,
- development of a response plan for the purpose of mitigating personal exposure when dust controls are non-compliant,
- discussion of the effectiveness of dust control measures into pre-start shift meetings,
- systematic review and continuous oversight of the effectiveness of controls by competent ventilation engineers and Occupational Hygienists,
- only using competent personnel to inspect, maintain, and monitor controls and equipment.

19.2 Controlling exposure

Planning

The most effective way to prevent silica-related disease is to eliminate exposure to RCS. This requires careful planning to prevent or avoid dust generation wherever practicable. If elimination is not reasonably practicable, then risks must be minimised in accordance with the requirements of Part 3.1 of the WHS Regulation which includes applying the hierarchy of controls. By addressing RCS risks during health and safety in design processes, tunnelling projects can substantially reduce dust at the source and avoid over-reliance on less effective administrative and PPE control measures.

Examples of control measures that should be considered during the design and planning phase include:

- Designing cast-in systems (such as channels or ferrules) into precast tunnel lining to allow anchor installation, thereby removing the need for manual or automated drilling into the lining after it is installed.
- Automating drilling operations through using drilling robots fitted with on-tool High Efficiency Particulate Air (HEPA) extraction, rather than through hand-held drilling.
- Substitution of high-crystalline silica containing substances with those that contain no or low crystalline silica (e.g. no or low-silica grout).
- Designing excavation sequences, plant and equipment to minimise worker exposure to dust. This should include an assessment of the interaction between the method, dust generation sources, ventilation, extraction and/or suppression systems and other engineering and administrative controls including remote operation of excavation plant and equipment. Any changes to the method, sequence, plant or equipment which results in a reduction in dust control effectiveness (including dust suppression or maintenance issues) will require a review of the control measure to ensure the risk is effectively minimised.
- Temporary roadways for underground plant movements have considerable potential to re-mobilise dust generated by preceding work activities. Accordingly, the type of plant used, the required frequency of plant movement and effects on dust generation should be considered as part of planning for construction logistics, spoil and personnel transport systems and tunnel construction method options. This may, for example, favour the use of conveyors instead of wheel-based plant for many health and safety risk management reasons, not just RCS control. However, where conveyors are not practicable, sealing

temporary road surfaces underground can minimise dust remobilisation when used with water sprinkler dust suppression systems and may be adopted subject to development of suitable systems of collection, control and disposal of contaminated drainage run off.

Enclosures

Enclosed cabins on mobile plant are engineered to isolate workers from air that is contaminated with airborne particles. Protection against dusts and RCS depends on the effectiveness of filters, preventing internal contamination of the enclosed cabin and ensuring the integrity of the seals for all openings of the enclosure. Regular inspection, testing, monitoring and maintenance by the PCBU is required to ensure these control measures remain effective.

For RCS control, all enclosed cabins should be fitted with a high-efficiency air filtration system. The enclosed cabin should be engineered with filtration systems with sufficient sealing capacity to achieve positive pressurisation against contaminant penetration. Australian/New Zealand Standard *AS/NZS ISO 23875:2023 - Mining – Air quality control systems for operator enclosures – Performance requirements and test methods* sets minimum standards for:

- pressurisation of cabins to prevent ingress of contaminants,
- control of respirable particulate matter,
- monitoring and control of carbon dioxide (CO_2) concentrations.

Where the emission of RCS arises from the operation of an excavator, roadheader or other machine, the operator of that machine should be protected by an enclosed cabin that meets the requirements of *AS/NZS ISO 23875:2023*. PCBUs in consultation with their workers, HSRs, and Occupational Hygienists, may identify other suitably effective control measures that can be implemented to effectively minimise risks.

The principles of *AS/NZS ISO 23875* may also be applied to other enclosed underground spaces such as crib rooms and respite stations to control airborne contaminants, including RCS. This includes high-efficiency air filtration systems, positive pressurisation and associated pressure monitoring, and continuous air quality monitoring. Workers should have access to respite areas underground, including ensuring that they can safely decontaminate and remove RPE e.g. prior to eating and drinking.

Seats and other soft furnishings in tunnelling plant and equipment should be made from impervious materials, or be fitted with impervious covers e.g. plastic, as fabric surfaces can accumulate dust, including RCS and other contaminants. Fabric is difficult to clean effectively and can release dust back into the air when disturbed, increasing the risk of worker exposure. Impervious materials and plastic covers are easier to clean, allow for regular decontamination, and reduce the accumulation and re-suspension of hazardous dusts.

Operating procedures for underground excavation work should incorporate requirements for exiting enclosures to allow sufficient time for external dust extraction systems to remove airborne dust. These requirements should also be considered when developing emergency plans and evacuation protocols.

Dust suppression

Dust suppression involves the wetting of airborne contaminants such that the weight of each airborne particle increases, thus decreasing the airborne contaminant's ability to remain in the air. Droplet size is a critical consideration when selecting wet dust suppression systems as too large a droplet size may not control the dust particles.

Fixed dust suppression sprays should be installed where dusts may be generated, such as:

- on transfer points of conveyor systems, where materials drop on to other conveyor belts,
- within structures designed to house the storage and transport of spoil,
- within tunnels to minimise disturbance of deposited dust located in the tunnel invert by tunnel traffic movement (e.g. misting water spray bars).

Other uses of dust suppression include:

- wet drilling,
- integrating dust suppression on mobile plant that generate dust – for example, breakers, hammers, saws,
- wetting spoil heaps after blasting and while loading,
- wetting muck piles,
- using water carts to wet down roadways,
- washing down cutting picks prior to changing out,
- washing down vent cans prior to relocation,
- washing down walkways and stairs regularly,
- washing down the TBM regularly.

On-tool dust suppression and extraction

To assist in effectively managing the risk of RCS exposure, power tools generating RCS should be fitted with effective wet dust suppression, on-tool extraction and collection, or used with an effective local exhaust ventilation system. Dust extractors/vacuums used with power tools should meet the M- or H-Class requirements of Australian/New Zealand Standard *AS/NZS 60335.2.69:2017 – Household and similar electrical appliances – Safety* and used in accordance with manufacturers' instructions.

Housekeeping and decontamination

RCS can settle on floors, equipment and workers' clothing, from where it may readily become airborne and inhaled. Regular cleaning is required to prevent the build-up and re-suspension of dust.

Cleaning should include floors, walls, scaffolds, plant, tools, vehicle cabins, common areas and walkways, and should be undertaken as often as required to effectively control dust.

Cleaning should be carried out using wet methods (such as wet vacuuming, damp wiping or hosing down) or using vacuum extraction equipment suitable for controlling RCS. Some activities will require vacuum equipment that provides higher levels of filtration and containment, such as H-Class or M-Class vacuums.

Vacuum and extraction equipment should be selected, inspected, maintained and tested in accordance with manufacturers' instructions and relevant standards to ensure it remains effective in controlling dust exposure.

Dry sweeping, the use of compressed air or blowers, and high-pressure water blasters should not be used to remove dusts that may contain RCS.

Decontamination and laundry facilities should be provided for tunnelling and excavation workers to reduce the potential for cross-contamination of dust into other areas. Decontamination and laundry arrangements should be assessed and controlled as part of the risk management process and supported by appropriate training and supervision.

Restriction and exclusion zones

Dust control zones may be used to isolate high dust exposure areas with specific safe work methods required for workers to enter designated dust control zones. Access should be subject to entry control procedures such that access is restricted during high dust activities e.g. excavating, shotcreting, and overhead drilling.

Work scheduling

Workers may be exposed to RCS either directly from tasks they are performing, or indirectly from nearby activities, such as being positioned downwind of dust-generating work.

Activities known to generate significant airborne contamination should be scheduled at times when the fewest workers are present, and when the least number of workers are likely to be exposed.

When planning work that generates airborne contaminants, the PCBUs should apply the following principles:

i. establish dust control exclusion and restricted zones,

ii. assign the smallest number of workers necessary to complete the task safely,

iii. rotate workers within crews to reduce the duration of individual exposures,

iv. reschedule nearby work to prevent exposure.

Control measures relevant to conventional tunnelling

Conventional tunnelling activities present a high risk of worker exposure to RCS. Effective dust control requires careful planning by PCBUs and the consistent application of engineering, isolation, administrative and PPE measures across excavation, support and spoil handling.

Ventilation and dilution with fresh air are critical control measures, (refer Chapters 16 and 17) and sufficient fresh air should be supplied in accordance with project-specific ventilation plans.

Extraction systems such as scrubbers should be advanced prior to cutting to support effective dust removal and prevent rollback over the operator's cabin, with placement at the front of the roadheader to avoid dust engulfing the cabin.

Ventilation ducting, fans and vent bags must be regularly inspected and maintained, and shutdown procedures implemented to prevent dust accumulation in the event of fan stoppage.

Substitution methods, such as using remote-controlled equipment for breaking or cutting, should be adopted where practicable.

Isolation controls are also essential, including maintaining positive pressure in work areas and operator cabs, installing brattice with dedicated ventilation to prevent secondary exposures, and cabins meeting the requirements of Australian/New Zealand Standard *AS/NZS ISO 23875:2023 – Mining – Air quality control systems for operator enclosures – Performance requirements and test methods*. Cabins should be cleaned using wet methods or M- or H-Class vacuums.

Dust suppression and extraction systems should be fitted to roadheaders, excavators and other dust-generating tools, targeting both the cutting head and rear tail conveyor, and roadway dust should be suppressed through regular wetting by water carts.

Where blow piping or blinding is necessary, dual compressed air–water systems should be used.

Work sequencing should minimise worker presence in dusty areas and avoid overlapping activities that increase secondary exposure, supported by adequate supervision and oversight, to ensure all dust controls are applied correctly and consistently.

Control measures relevant to TBM tunnelling

Careful consideration of RCS controls is required at the design stage of a TBM project and throughout construction. The design of a TBM should minimise the need for retrofitting by ensuring the TBM can effectively supply fresh air and extract contaminated air containing RCS. Ventilation systems should be engineered to capture and remove dust at the point of generation, maintain sufficient airflow throughout the tunnel, and protect workers both inside the TBM and along the tunnel alignment.

The design should also provide areas on the TBM, such as the operator's cabin and crib rooms, where RPE can be safely removed. These areas are likely to require HEPA filtration, positive pressure, and continuous air quality monitoring to enable the removal of RPE.

Regular washdowns of the TBM and other machinery should be carried out to prevent the accumulation of dust and debris.

Following each TBM breakthrough, and before any maintenance work begins, the TBM should be washed down to reduce the risk of worker exposure to dust that may be released when deposits are disturbed.

Where compressed air use on crystalline silica substances cannot be reasonably avoided, such as at the TBM Quick Unloader area, compressed air and water may be used to clean dust and debris from segments to ensure safe operation of the vacuum lifter. To minimise airborne RCS, segments should be hosed down with water before compressed air is applied, and appropriate extraction ventilation and RPE should be provided.

Real time air quality monitoring for RCS

Real-time or direct-reading monitoring devices provide continuous measurement of dust levels, offering immediate feedback on worker exposures and the effectiveness of control measures. Because respirable dust and RCS particles are so small that they are invisible to the naked eye, these devices are useful for detecting exposure risks that workers cannot see. These devices allow for early identification of high exposure tasks, activities, or work areas and support timely intervention to prevent exposure. While they are not a substitute for compliance sampling, direct-reading monitoring devices are a valuable tool for managing dust risks in tunnelling, particularly when used alongside personal monitoring. Their use should be incorporated into dust control programs to verify the performance of engineering controls, guide work practices, and provide workers with greater awareness of dust exposure in real time.

When real-time monitoring is used, the results do not typically specify RCS levels. To estimate RCS exposure, a correction factor is applied to the respirable dust fraction based on the proportion of RCS in the dust. The correction factor applied in real-time dust monitoring should be specific to the material and task. For example, a Safety Data Sheet for concrete may indicate it contains 30 per cent crystalline silica, which would be used as the minimum correction factor when cutting into that product. For natural materials such as sandstone or shale, crystalline silica content should be obtained from geotechnical reports. Where multiple sources of RCS are present, the highest proportion of crystalline silica is typically applied. Previous exposure data collected by an Occupational Hygienist for similar work activities can also help determine an appropriate correction factor. The Occupational Hygienist should determine and document the correction factor(s) used.

Typical activities where real time monitoring is used include:

- after blasting, to determine when it is safe for workers to re-enter the tunnel,
- during workplace inspections to detect if control measures are operating as designed,
- to determine RCS levels from changes in work activities,
- during personal air monitoring to identify high exposure tasks.

19.3 Health monitoring

PCBUs should refer to the *Code of practice: Managing risks of respirable crystalline silica in the workplace* for detailed information on health monitoring requirements for RCS.

Schedule 14 Table 14.1 of the WHS Regulation requirements for health monitoring for crystalline silica are:

- demographic, medical and occupational history,
- records of personal exposure,
- standardised respiratory questionnaire,
- standardised respiratory function test (e.g. FEV1, FVC and FEV1/FVC),
- chest X-ray full size PA view.

All full size PA chest X-rays should be taken and read consistent with ILO guidelines by a B reader or a radiologist trained under Royal Australian and New Zealand College of Radiologists approved training equivalent to the B Reader accreditation. A 'B-reader' is a radiologist trained to detect dust lung diseases such as silicosis, coal workers' pneumoconiosis, mixed dust pneumoconiosis and progressive massive fibrosis.

All lung function tests should be performed according to the Thoracic Society of Australia and New Zealand (TSANZ).

Safe Work Australia's *Health monitoring guide for Crystalline Silica* provides further information on frequency of chest X-rays.

High-resolution computed tomography (HRCT) has been demonstrated to be more sensitive than X-rays in detecting early dust lung disease. Use of a HRCT scan of the chest may be considered instead of a chest X-ray depending on the worker's history and levels of exposure.

19.4 Silica worker register

Under Part 8A.4 of the WHS Regulation, PCBUs must register each relevant worker within 28 days of them commencing high-risk crystalline silica substance (CSS) processing work. Only workers undertaking high-risk CSS processing on or after 1 October 2025 need to be registered. PCBUs only need to notify each worker to the register once during their employment with the business.

PCBUs must provide the following details about their business to the Silica worker register:

- PCBU name,
- ABN,
- PCBU contact name,
- contact phone number,
- contact email address,
- registered business address,
- workers compensation policy number, if applicable,
- industry type.

For each worker that undertakes high-risk CSS processing, a PCBU must provide the following details:

- worker's name,
- worker's phone number,

- worker's email address,
- worker's date of birth,
- whether a person other than icare was engaged to provide health monitoring for the worker, and if so, the person's business name and ABN.

A PCBU must provide the following information about the processing of high-risk CSS:

- date the processing commenced,
- site address where the high-risk CSS are processed, and
- whether the processing work is related to tunnel construction (and, if so, the project name).

PCBUs are only required to register workers they direct or allow to carry out the processing of a CSS that is high risk. For example, Principal Contractors on a construction site are not required to register the workers of a subcontractor as it is the subcontractor that is directing or allowing those workers to carry out the processing of a CSS that is high risk. The subcontractor is responsible for registering their workers, in this example. It is recommended that a Principal Contractor confirms with its subcontractor(s) that they have met their obligation of notifying to the Silica worker register. PCBUs operating in an industry regulated under the *Coal Industry Act 2001* are not required to notify their workers to the Silica worker register. For further information, see SafeWork NSW's *Silica worker register notification*.

20. Incident notification and internal reporting

20.1 Incident notification

Part 3 of the WHS Act,

WHS Act section 35

What is a "notifiable incident"

WHS Act section 38

Duty to notify of notifiable incidents

A 'notifiable incident' is:

- the death of a person,
- a 'serious injury or illness', or
- a 'dangerous incident' that exposes someone to a serious risk (even if no one is injured)

arising out of the conduct of a business or undertaking at a workplace.

'Notifiable incidents' may relate to any person - whether an employee, contractor or member of the public.

A PCBU must ensure that SafeWork NSW is notified immediately after becoming aware that a notifiable incident arising out of the conduct of the business or undertaking has occurred. Notifications can be made by contacting SafeWork NSW on 13 10 50 or via the SafeWork NSW website: *Notify SafeWork*.

The person with management or control of a workplace at which a notifiable incident has occurred must ensure, so far as is reasonably practicable, that the site where the incident occurred is not disturbed until an inspector arrives at the site or any earlier time that an inspector directs. This doesn't prevent assistance being provided to an injured person, removing a deceased person, making the site safe or to minimise the risk of a further notifiable incident, or to facilitate a police investigation.

Enforcement action may be taken and penalties may be applied for not notifying notifiable incidents to SafeWork NSW.

Incidents involving multiple businesses or undertakings

If a 'notifiable incident' arises out of the conduct of more than one business or undertaking then each must ensure that the incident has been notified to SafeWork NSW.

All duty holders have a responsibility to ensure SafeWork NSW is notified. They may discharge this duty by agreeing that one duty holder will notify SafeWork NSW, but this does not remove their individual obligation.

In these circumstances the duty holders must, so far as is reasonably practicable, consult, cooperate and coordinate to put appropriate reporting and notification arrangements in place.

For more information

Refer to the SafeWork NSW *Incident notification in NSW - information sheet*.

20.2 Internal reporting

Under NSW Workers Compensation legislation, a register of injuries must be maintained and accessible to all workers. The register must include details such as the name of the injured person, date and time of the incident, nature and cause of the injury.

All incidents, regardless of severity, should be responded to promptly to ensure the safety of all workers. All incident investigations and corrective actions should be documented and retained.

Incidents should be investigated and addressed through corrective actions to prevent reoccurrence. Workers should be encouraged to report hazards or unsafe behaviours without fear of reprisal.

21. Emergency planning and preparedness

21.1 Preparation and maintenance of the Emergency Plan

Under section 43 of the WHS Regulation (Duty to prepare, maintain and implement emergency plan), a PCBU must prepare an emergency plan for the workplace that includes:

- an effective response to emergencies,
- evacuation procedures,
- notifying emergency services organisations at the earliest opportunity,
- medical treatment and assistance,
- effective communication between the emergency coordinator and all persons at the workplace,
- testing of emergency procedures, including frequency of testing, to assess response times and identify lessons learned,
- information, training, and instruction for relevant workers on implementing the emergency procedures.

PCBUs must maintain the emergency plan for the workplace so that it remains effective.

In preparing and maintaining the emergency plan, the PCBU must have regard to all relevant matters including:

- nature of the work being carried out,
- nature of the hazards at the workplace,
- size and location of the workplace,
- number and composition of workers and other persons present at the workplace.

Where a workplace is shared by multiple duty holders the emergency plan must be developed through consultation and cooperation with all relevant parties, including workers and HSRs. The person with management or control of the workplace, typically the Principal Contractor, should coordinate this consultation process and include emergency services in the consultation.

A site-specific Emergency Management Plan (EMP) must be developed and may be included in the Safety Management System. This should:

- identify potential emergencies and define response strategies,
- ensure the EMP is accessible to all workers and emergency services,
- regularly review and update the EMP based on operational changes or incidents.

The emergency plan must be updated as works progress so that it remains relevant and effective.

All types of emergency and rescue scenarios should be considered when developing emergency procedures. Information from risk assessments will assist in this task. Emergency plans will be interdependent with control measures implemented. Table 10 sets out some questions to consider when establishing emergency procedures.

Following an incident, immediate actions should include securing the site, providing first aid, and preventing further harm. A designated incident controller should coordinate the response and ensure communication with emergency services if required.

Table 10: Developing emergency procedures

Issue	Considerations
Coverage of plan	How will the safety of people at the workplace including visitors or people who need help to evacuate in an emergency, be considered in the plan?
Emergency events	What emergencies could happen? What control measures can be implemented to reduce the severity of the emergency? What equipment will be needed to identify and manage emergencies? What specific elements and procedures should be included to maintain critical functions?
Evacuations	What situation or circumstances should trigger an evacuation? How will the controlled evacuation of people from the workplace be handled? Are the personnel underground trained in the emergency evacuation procedures? When was the last emergency evacuation drill undertaken? Are there any lessons learned from previous drills that need to be incorporated into the procedures?
Workplace location	Is the work carried out in a remote or isolated place? How accessible is it in an emergency and how far away is it from medical facilities? Can a person be rescued immediately without relying on emergency services? Are there areas where special emergency provisions and the means to extract people from difficult locations like the base of a shaft are needed? Have safe places and assembly points been identified?
Escape routes	Refer to Table 11 for questions and information on escape routes.
Roles and responsibilities	Who should be allocated roles and responsibilities in an emergency e.g. area wardens? Who has the relevant skills for specific actions in an emergency?
Training	Who requires regular and on-going training? When should this be provided? Does the training include an understanding of the emergency plan and actions to be taken in an emergency, escape options and emergency equipment? How will workers who enter the tunnel be trained in entrapped procedures, like remaining calm, alert and making conservative decisions?
Communication	How: – Can workers doing tunnelling work communicate in an emergency? – Will clear lines of communication between the person authorised to co-ordinate the emergency response and people at the workplace be maintained? and – Will alarms be activated and who will notify people at the workplace? Is there a system in place to identify who is underground, like tag boards or electronic tagging? Have you clearly displayed the workplace site plan showing where fire protection equipment is stored, the location of emergency exits, assembly points and emergency phone numbers?

Issue	Considerations
Rescue equipment	Has rescue equipment been selected based on the nature of the work and the control measures used? Can it carry out the planned emergency procedures? Is rescue equipment kept close to the work area so it can be used quickly?
Capabilities of rescuers	Are rescuers properly trained, fit to carry out their task and capable of using rescue equipment? Have emergency procedures been tested to demonstrate they are effective?
First aid	Have first aid requirements been assessed and implemented? Is first aid available for injuries associated with falls, cuts and crush injuries? Are trained first aiders available to use the equipment?
Consulting, cooperating and coordinating with local emergency services	Are the emergency procedures co-ordinated with local emergency services? If not, why? Does the emergency plan include the emergency services involvement in a trial rescue early in the construction? How will the local emergency services be notified of an incident? Can you ensure that the necessary accurate information is available to emergency services if needed?
Administration, maintenance and review	Does the emergency plan contain instructions on how it is to be administered, maintained and reviewed and how workers will be involved in these reviews?

Once established, a competent person should regularly report to the Client Organisation on the measures in place for the prevention and management of emergency events such as fires and explosions, flooding, chemical release, gassing, or engineering emergencies and the circumstances under which evacuation is required such as the failure of critical safety systems.

21.2 Escape and rescue

Rescue procedures including the circumstances for self-rescue and where rescue will be assisted should be described in detail in the emergency plan. PCBUs should regularly test emergency plans to maintain effectiveness and must ensure workers are provided with the appropriate information, training and instruction. There should be sufficient equipment and infrastructure to accommodate the maximum number of people who may be at risk in an emergency. Further considerations are provided in Table 11 below.

Table 11: Escape route planning

Issue	Considerations
Identifying escape routes	Have all: • possible escape routes like parallel tunnels, shafts or other connections to the surface been identified? • escape routes been clearly marked? • escape routes that maintain fresh air flow during a fire emergency been identified? Have you considered control measures to ensure the integrity of escape routes or safe places in an emergency? Are escape routes dimensions suitable for stretchers and rescue teams? What is the impact of low visibility during an emergency? Is there sufficient strategic placement of emergency lighting and ropes or chains to guide workers?
Securing an immediate supply of respirable air and Self-Contained Self-Rescuers (SCSRs)	How will an immediate supply of emergency respirable air for workers be provided and maintained for the duration of the emergency, or that will enable self-rescue? When developing escape routes while using SCSRs have you assessed how far a person, in a reasonable state of physical fitness, can travel?
Refuge chambers (where provided - see Chapter 21.4)	An underground refuge chamber provides a safe place for people if the atmosphere becomes unbreathable. When choosing where to put a refuge chamber and how many to put in, have you taken into account: • the risks from the work activities? • how long it will take workers to get to the chamber from where they are working? • whether it can fit everyone in and is there an effective communication system inside? • how long the air will last based on a risk assessment? Does the risk assessment take into account types of emergencies e.g. fire as well as equipment, accessibility, alternative air supplies and how long it takes to get to safety?

Issue	Considerations
Vehicles and plant in the tunnel	How: • have the risks from vehicles and plant contributing to an emergency been addressed in the emergency plan? • will workers be provided with information, instruction and training for operating plant to keep escape routes and emergency entry clear?
Escape route signage	Are emergency escape route signs legible and understood? Further information on signage maintenance and marking is in Australian Standard *AS 1319-1994: Safety signs for the occupational environment*.

21.3 Injured persons

A suitable means should be provided for hoisting injured persons from any shaft.

21.4 Refuges and changeover stations

The emergency plan should include consideration of the location and suitability of refuges and emergency egress arrangements, including travel distances from any place of work, escape route gradients, staircases and scaffold egress, distances of in bye workings relative to the shaft or surface portal, heat and humidity, physical limitations of individuals, and incident characteristics.

Emergency planning requirements should also be considered in the design phase. Feasibility and suitability should be assessed as part of the safety in design risk assessment during tunnel feasibility studies, noting that spatial constraints in smaller diameter tunnels may limit their practicability.

22. Fire and smoke control

22.1 Overview

The consequences from underground fires can be more serious than for similar fires on the surface.

Fire underground rapidly consumes oxygen and produces noxious fumes and gases making an atmosphere irrespirable. Any fire will produce smoke that will reduce or eliminate visibility and hinder egress by blocking exit pathways.

Risks from fire and smoke must be eliminated or minimised so far as reasonably practicable. Controls include:

- minimising the fuel load though controlling the availability of fuel and combustible materials, e.g. non-flammable hydraulic oils, fire-resistant belt conveyors, etc.,
- controlling the sources of ignition e.g. electrical installations, electrical faults, plant, hot works etc.,
- regular and routine inspections of fixed installations and plant,
- only use plant that is assessed and approved for the site by the PCBU,
- plant should incorporate measures to minimise fire risk, e.g. fixed fire suppression systems and the use of non-combustible or fire-resistant materials,
- use of control procedures such as 'hot works' permits,
- maintenance and testing of fire control systems and equipment,
- monitoring and assessment, especially gas monitoring to detect hazardous atmospheres,
- fire and smoke risks assessed by a person competent in fire and smoke risk assessment for underground works, with the level of expertise proportionate to the scale and complexity of the fire risk. This should be included as part of the project's overall risk assessments and emergency planning processes.
- establishing clear and co-ordinated emergency procedures (refer Chapter 21).

The following table outlines considerations, questions, hazards, risks, and control measures related to fire and explosion safety.

Table 12: Fire and explosion safety considerations

Issue	Considerations
Combustible materials and sources of ignition	• What are the potential ignition sources? • How can the volume of combustible and flammable materials, such as from waste be minimised? • Has a hot work permit been issued? • Is all electrical equipment tagged for use? • Is all diesel plant maintained and suppression systems functioning correctly? • Are there sources of static electricity? • Is smoking and vaping prohibited on site? • Are sources of ignition such as lighters considered contraband?

Issue	Considerations
Fire-fighting facilities	• What fire-fighting equipment should be available? • Who is competent to use it, and where should it be located?
Training	• How will training upon basic awareness of fire hazards and fire prevention be delivered? • Does the training include: — the selection and use of extinguishers, — when and how to use self-rescuers and their limitations, — safe use of refuge chambers if present, — hot work permit system requirements?

22.2 Hot works and firewatching

Given the high risk of fire associated with welding and cutting of steel, these activities should, where practicable, be undertaken at the surface or replaced with cold processes underground.

Welding, the process of permanently joining two or more materials together by heat or pressure or both, 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, and exposure to intense ultraviolet radiation (source: *Code of practice: Welding processes*).

Hazards that could give rise to health and safety risks must be identified. This identification should be conducted by a team of knowledgeable and competent persons, including those who have demonstrable knowledge, experience and skills in facilitating risk assessments and persons who have subject matter expertise in the hot-work related activity such as welding or cutting.

Different hot works processes also influence the risk. For example, the risk of electric shock is lower using gas metal arc welding (GMAW) than manual metal arc welding based on the fact that the open circuit voltages are lower, only direct current is used and the power is switched off at the hand piece.

In order to minimise risks from hot works PCBUs should develop and implement a 'hot work permit system' if they are unable to eliminate the risk. Guidance on hot work permit systems can be obtained from Australian Standard *AS 1674.1:2025 – Safety in welding and allied processes – Part 1: Fire precautions*. The purpose of a hot work permit system is to identify all potential hazards associated with the proposed hot work activity and to control any associated risks.

The system should specify the conditions for storage, transport and use of equipment, the fire prevention precautions required, the roles and responsibilities of workers including the designated responsibility for issuing a written hot work permit, and the control measures required for the hot work to ensure the safety of persons in the vicinity. The system should also cover the return of the equipment to surface storage.

Hot work permits should be time and date specific. Considerations prior to issuing the permit include:

- flammable atmosphere, gases and dusts,
- flammable and combustible materials,
- access and egress locations,
- adequate ventilation,

- exclusion or restricted access zones,
- identification, protection, and/or isolation of services,
- fire precautions e.g. non-flammable covers or screens,
- identifying firewatch requirements during and after hot works,
- suitable fire-fighting equipment, making sure it is available and tested prior to hot work being undertaken.

Specific procedures for welding or cutting in a hazardous atmosphere or hazardous area should be considered and developed. For example, the WHS Regulation requires a 'confined spaces entry permit' for work in a confined space. When welding in an area that is not a confined space, specific procedures should still be documented ensuring that all activities are covered by a relevant SWMS.

A hot work permit system should require a firewatcher to be in attendance whenever a hot work permit has been issued. Responsibilities of the firewatcher include continuously monitoring the area during hot work, remaining on site for at least 30 minutes after completion of the hot work and ensuring the correct fire-fighting equipment is present and accessible throughout the hot work permit duration.

23. Use of Personal Protective Equipment (PPE)

23.1 Overview

WHS Regulation section 44

Provision to workers and use of personal protective equipment

PPE cannot be relied on as the only way to minimise risk. It can only be used to minimise any remaining risks that cannot be controlled by higher level control measures e.g. engineering, isolation, substitution. When and how to use PPE should be specified in the site specific safety management plan.

If PPE is to be used at the workplace, the PCBU must ensure the equipment is:

- selected to minimise risk to health and safety, including by ensuring that the equipment is suitable for the nature of the work and any hazard associated with the work and is of suitable size and fit and reasonably comfortable for the worker who is to use or wear it,
- maintained, repaired and replaced so that it continues to minimise risk to the worker who uses it, including by ensuring that the equipment is clean and hygienic, and in good working order.

The PCBU who directs the carrying out of work must provide the worker with information, training and instruction in the proper use and wearing of PPE, and the storage and maintenance of PPE.

A worker must, so far as reasonably able, use or wear the PPE in accordance with any information, training or reasonable instruction and must not intentionally misuse or damage the equipment. Facilities for cleaning and storing PPE should be provided. Maintenance including cleaning and/or replacement should be managed with records kept.

Note: Respiratory Protective Equipment (RPE) should be considered only after all other higher-order control measures have been evaluated and applied (refer Chapter 23.6).

23.2 Head protection

All persons on site should wear suitable head protection at all times in accordance with Australian/New Zealand Standard *AS/NZS 1801: Occupational protective helmets* and Australian/New Zealand Standard *AS/NZS 1800:1998 - Occupational protective helmets – Selection, care and use*.

Head protection must have suitable and compatible cap lamps provided where required, especially for underground work.

23.3 Foot protection

Footwear should be worn at all times in accordance with Australian/New Zealand Standard *AS/NZS 2210.1:2025 - Safety and occupational footwear*.

23.4 Hand protection

Gloves should be worn where a person is at risk from cuts, abrasions or puncture injuries in accordance with Australian/New Zealand Standard *AS/NZS 2161.1:2016 - Occupational protective gloves*. Pre-work (barrier) creams should be made available and used by site personnel. Moisturisers and adequate facilities for good skin hygiene should also be provided.

23.5 Eye protection

The selection, use and maintenance of eye and face protection should be in accordance with the following Australian/New Zealand Standards:

- *AS/NZS 1337.1:2010 - Personal eye protection – Eye and face protectors for occupational applications*
- *AS/NZS 1337.2:2012 - Personal eye protection - Mesh eye and face protectors for occupational applications*
- *AS/NZS 1337.6:2012 - Personal eye protection - Prescription eye protectors against low and medium impact.*

Where eye protection is required to be worn throughout the working shift, optical quality lenses should be used. PCBUs must establish arrangements for ensuring the provision of safety glasses fitted with prescription lenses for workers who require optical corrective lenses.

Safety goggles, face shields or fixed shields should be worn by site personnel. This includes working with pressurised air and water cleaning, spraying concrete, grinding or chipping, metal cutting, grout mixing and placing, breaking, cutting or drilling concrete or stone or similar material, and by persons handling or injecting hazardous liquids under pressure. For protection whilst undertaking hot works, additional protection should be used.

23.6 Respiratory protection

Like any other PPE, respiratory protective equipment (RPE) can only be used after all other higher level control measures for airborne contaminants under the hierarchy of controls have been applied. RPE is the lowest form of control for airborne contaminants and is not always reliable in practice. Tunnel worker exposures to airborne contaminants such as RCS have occurred due to the deficiencies in the effectiveness of higher level control measures, absence of fit testing, interference from facial hair, and the use of RPE with insufficient protection factors.

Where RPE is used to minimise the risk to health and safety the PCBU providing the RPE must ensure that the equipment is:

(a) suitable regarding the nature of the work and any hazard associated with the work,

(b) of a suitable size, fit and comfort for the worker,

(c) clean and hygienic,

(d) in good working order.

RPE should comply with Australian/New Zealand Standard *AS/NZS 1716:2012: Respiratory protective devices* and should be selected, used and maintained in accordance with Australian/New Zealand *Standard AS/NZS 1715:2009: Selection, use and maintenance of respiratory protective equipment*. This is to ensure that the RPE is suitable for the nature of the work and any associated hazards. Refer to *AS/NZS 1715:2009* for factors that should be considered when selecting and using RPE, which include whether the worker has facial hair, comfort, fit and compatibility with other PPE.

For tight fitting RPE, an adequate face seal is required to prevent contaminants leaking into the respirator, and workers must be clean shaven if their facial hair will interfere with the face seal. Otherwise, workers with facial hair may be provided with loose fitting head top powered air purifying respirators which do not rely on a tight-fitting face seal.

Quantitative fit testing should be carried out by a competent person (e.g. a RESP-FIT accredited Fit Tester) to ensure workers can achieve an adequate face seal with close fitting facepieces (also referred to as masks). Fit testing should be carried out before the respirator is used and then should be done annually, or as soon as

practicable if the wearer's facial features change which affect the face seal. The assessment and determination of requirements for and selection of RPE for each task and SEG should be carried out under the supervision of an Occupational Hygienist.

Underground workers should be provided with RPE that has a minimum protection factor of 50, unless a risk assessment involving an Occupational Hygienist determines that a different level of protection is appropriate.

When selecting RPE, PCBUs should take into account the need for workers to communicate effectively. RPE can affect a worker's ability to speak, hear, or be heard, which may create additional risks, particularly in high-noise or safety-critical environments such as tunnelling. Selection should prioritise RPE that maintains both protection and communication, for example through designs that minimise speech interference or by incorporating compatible communication systems.

If RPE is provided, control procedures for charging (as required), storage, maintenance and repair facilities for RPE should be developed.

PCBUs should also refer to *Code of practice: Managing risks of respirable crystalline silica in the workplace* for further information.

23.7 Hearing protection

Personal hearing protectors should be selected and maintained in accordance with Australian/New Zealand Standard *AS/NZS 1269.3:2005: Occupational noise management – Hearing protector program*. PCBUs should involve workers in the selection process and offer a reasonable choice from a range of types.

When workers are required to wear both hearing protection and RPE, the two should be compatible. Poorly matched equipment can reduce the effectiveness of the respirator seal or the hearing protector's attenuation. It is equally important that workers are still able to communicate clearly and hear warning signals while using both. Where possible, integrated solutions or compatible systems should be selected to ensure protection is maintained without reducing operational effectiveness.

PCBUs should refer to the *Code of practice: Managing noise and preventing hearing loss at work* for further information.

23.8 Whole-body protection

Selection of clothing must be suitable to assist in controlling the risk e.g. the provision of flame retardant clothing. Additional protective clothing should be provided and used where appropriate to the risk, for example in excessively wet conditions, when undertaking hot works, when handling hazardous substances or working in contaminated ground. High visibility requirements should be in accordance with Australian/New Zealand Standard *AS/NZS 4602.1:2024 - High visibility safety garments – Garments for high risk applications*.

23.9 Self-Contained Self-Rescuers (SCSR)

Everyone working underground should be trained in the use of SCSR where provided (see Chapter 6.2 in this Code).

The location of the SCSRs and whether they are to be carried or not should be determined by risk assessment in consultation with workers and re-evaluated during pre-start meetings or reviews of control measures.

If the nature of the work is such that carrying an SCSR incurs a risk due to a confined working area, then a risk assessment may identify that the SCSR may be located at a suitable place within easy reach of the worker's work location. PCBUs should ensure workers are aware of the location of the supply of SCSR at all times if they are not being carried.

Where there is a foreseeable risk of smoke, fire, or toxic gas and where safe egress conditions cannot be assured before the onset of an Irrespirable Atmosphere, then all persons underground should have immediate access to an oxygen SCSR.

An SCSR should provide the user with a supply of oxygen for at least 30 minutes nominal duration while walking. Where such oxygen supplies are likely to be needed for longer periods, stockpiles of additional SCSRs, possibly including longer duration and consequently heavier sets, should be provided at intervals determined in the emergency plan as informed by risk assessments and site emergency drills.

When planning for emergencies, a realistic assessment of likely speeds of escape is an essential consideration. Note that the air supply in the SCSRs will be used more quickly by agitated users, or when increased exertion occurs and physical difficulties are encountered while travelling. There are limitations to how long a wearer can endure wearing an SCSR in escape conditions and this must be factored into emergency planning. SCSR changeover should take place in a dedicated change-over station to allow workers to change SCSRs without exposure to a hazardous atmosphere.

Other persons, such as visitors in the workplace must be provided with information, training or reasonable instruction on SCSR use by the PCBU.

24. Tunnel repair and renovation

Undertaking tunnel renovation and repair may entail the majority of the risks described above for tunnel construction but with added complexity due to the operational status of many tunnels and the challenges of assessing aged infrastructure.

Similar to the construction for a new tunnel a systematic approach to risk management, including site-specific planning, ventilation, ground support, and supervision should be adopted by PCBUs. Other general principles shared with tunnel construction include:

- hazard identification and control using the hierarchy of controls,
- air quality management,
- emergency preparedness,
- competent supervision and training tailored to tunnel environments.

Tunnel repair and renovation differs in important ways from new construction.

- Uncertain condition of the existing structures, their relative strength, general condition and capacity reserves and response to loading or unloading and the potential presence of voids hidden behind lining due to the actions of groundwater. Typically, records of construction, prior repair or renovation are incomplete.
- Operational constraints: Many renovations occur during possessions (scheduled closures) or under live traffic/rail conditions, requiring precise coordination and minimisation of disruption.
- Legacy systems: Older tunnels may contain hazardous materials or require bespoke design solutions.

Renovation risk profiles vary significantly across tunnel types depending upon the asset management regime, operational environments and the associated risks. For example, rail tunnels will require close coordination with rail operators and may include track interface hazards and electrical hazards. Hydropower or sewer tunnels may be remotely located and may require dewatering and control of hydrogeological risks.

Remotely operated machines with cameras such as drones or submersibles may be useful in assessing conditions prior to the entry of any person.

Toxic gases, mixtures deficient in oxygen, or explosive mixtures can accumulate in unventilated tunnels, shafts, sumps or headings especially within old sewers and tunnels containing wastewater. Such risks are higher when disused or abandoned tunnels or shafts need to be entered, but they are also present when a tunnel or shaft is re-entered after a brief shutdown, such as a weekend.

Persons entering should be in possession of atmospheric monitoring and PPE having first established that conditions are safe to enter.

Additional workers should be on call and such operations should be planned on a “permit to work” and “confined spaces entry” basis.

Sewers, whether in use or abandoned, can be particularly hazardous and should be entered only with the approval of the local water authority and in accordance with their entry control procedures.

25. Appendices

Appendix A - Glossary

Terms used throughout this Code that require definitions or descriptions.

Term	Description
Client Organisation	The PCBU that commissions the construction work or project and/or the procurer of goods or services including design services whether a public entity or a private agency or developer.
Competent person	A person who has acquired through training, qualification or experience the knowledge and skills to carry out the task.
Confined space	An enclosed or partially enclosed space, other than a mine or the workings of a mine, that: • Is not designed or intended primarily to be occupied by a person, and • Is, or is designed or intended to be, at normal atmospheric pressure while any person is in the space, and • Is or is likely to be a risk to health and safety from: — An atmosphere that does not have a safe oxygen level, or — Contaminants including airborne gases, vapours, and dusts, that may cause injury from fire or explosion, or — Harmful concentrations of airborne contaminants, or — Engulfment
Contract agreement	For the purposes of this Code of practice, a contract agreement is a legally binding arrangement between parties that outlines roles, responsibilities, and obligations, including compliance with their respective duties under the work health and safety legislation, to ensure the health and safety of all persons involved in or affected by the contracted work. This may include: • Embedding non-delegable legal duties into contract terms. • Requiring certified safety systems and WHS plans. • Appointing a Principal Contractor with management or control of the workplace. • Developing effective consultation arrangements. • Ensuring WHS compliance through audits and reporting.
Crystalline Silica Substance (CSS)	A material contains at least 1% crystalline silica, determined as a weight/weight (w/w) concentration.

Term	Description
Dangerous incident	An incident in relation to a workplace that exposes a worker or any other person to a serious risk to a person's health or safety emanating from an immediate or imminent exposure to — (a) an uncontrolled escape, spillage or leakage of a substance, or (b) an uncontrolled implosion, explosion or fire, or (c) an uncontrolled escape of gas or steam, or (d) an uncontrolled escape of a pressurised substance, or (e) electric shock, or (f) he fall or release from a height of any plant, substance or thing, or (g) the collapse, overturning, failure or malfunction of, or damage to, any plant that is required to be authorised for use in accordance with the regulations, or (h) the collapse or partial collapse of a structure, or (i) the collapse or failure of an excavation or of any shoring supporting an excavation, or (j) the inrush of water, mud or gas in workings, in an underground excavation or tunnel, or (k) the interruption of the main system of ventilation in an underground excavation or tunnel, or (l) any other event prescribed by the regulations.
Designer	A PCBU that designs a structure that is to be used, or could reasonably be expected to be used, as or at a workplace including during construction, maintenance, renovation or demolition of a structure.
Dogger	A dogger is a person who performs dogging work.
Dogging work	Means: (a) the application of slinging techniques, including the selection and inspection of lifting gear, to safely sling a load, or (b) the directing of a plant operator in the movement of a load when the load is out of the operator's view. A valid High Risk Work (HRW) licence is required to perform the work outlined above. It can also be performed by a holder of a HRW licence for rigging work.
Duty holder	Any person who owes a work health and safety duty under the WHS Act including a PCBU, a designer, manufacturer, importer, supplier, installer of products or plant used at work (upstream duty holder), officer or a worker.
Fit for purpose	Something that is sufficient to do the function it was designed to do, for the intended use, over its specified design life.

Term	Description
Fresh Air	Air that contains sufficient oxygen, and is sufficiently free of airborne contaminants such as dust, fumes, vapours, gases, and mists, to sustain safe working conditions when used as part of a mechanical ventilation system (or available naturally) over the period of exposure whilst at work.
Hazard	A situation or thing that has the potential to harm a person. Hazards at work may include noisy machinery, moving plant, chemicals, particulates, electricity, working at heights, a repetitive job, bullying and violence at the workplace.
Hazardous atmosphere	Where the - • atmosphere does not have a safe oxygen level, or • the concentration of oxygen in the atmosphere increases the fire risk, or • the concentration of flammable gas, vapour, mist, or fumes exceeds 5 % of the lower explosive limit (LEL) for the gas, vapour, mist, or fumes, or • combustible dust is present in a quantity and form that would result in a hazardous area.
Health	Means physical and psychological health.
Health monitoring	Health monitoring, of a person, means monitoring of the person to identify changes in the person's health status because of exposure to certain substances
Health and Safety Committee	A consultative body established under the WHS Act. The committee's functions include facilitating cooperation between workers and the person conducting a business or undertaking to ensure workers' health and safety at work, and assisting to develop work health and safety standards, rules and procedures for the workplace.
Health and Safety Representative (HSR)	A worker who has been elected by their work group under the WHS Act to represent them on health and safety matters.
Health and safety risk management	A systematic approach to identifying health and safety risks, assessing and implementing controls, monitoring conditions and worker health, and consulting workers to prevent harm and promote well-being.
Heave	The displacement or swelling of soil or rock caused by the freezing and expansion of water. The freezing of water trapped in the ground's pores and fractures can lead to structural damage in construction and infrastructure.
Irrespirable atmosphere	An irrespirable atmosphere contains air that cannot be safely breathed due to insufficient oxygen or the presence of harmful substances such as toxic gases, smoke, or dust. Air is considered irrespirable when it: • contains less than 19.5% oxygen, or • contains toxic gases (e.g., carbon monoxide, hydrogen sulphide) at dangerous levels, or is contaminated with smoke, dust, or fumes that may exceed defined exposure limits.

Term	Description
Lithium batteries	Lithium batteries means the following – (a) Lithium-ion batteries, (b) Lithium-ion polymer batteries, (c) Lithium metal polymer batteries.
Lower explosive limit (LEL)	In relation to a flammable gas, vapour or mist, means the concentration of the gas, vapour or mist in air below which the propagation of a flame does not occur on contact with an ignition source.
May	'May' indicates an optional course of action.
Must	'Must' indicates a legal requirement exists that must be complied with.
Occupational Hygienist	An individual who is recognised as a Certified Occupational Hygienist (COH) by the Australian Institute of Occupational Hygienists (AIOH); or holds an equivalent competency under an international certification scheme (e.g. Certified Industrial Hygienist).
Officer	An officer under the WHS Act is: — an officer under section 9 of the *Corporations Act 2001* (Cth) — an officer of the Crown within the meaning of section 247 of the WHS Act, and — an officer of a public authority within the meaning of section 252 of the WHS Act. An elected member of a local authority while acting in that capacity, is not an 'officer'. A partner in a partnership is also not an officer, as each partner would be considered to be a PCBU.
Person conducting a business or undertaking (PCBU)	A PCBU is an umbrella concept which intends to capture all types of working arrangements or relationships. A PCBU includes a: • company • unincorporated body or association • sole trader or self-employed person. Individuals who are in a partnership that is conducting a business will individually and collectively be a PCBU. A volunteer association (defined under the WHS Act) or elected members of a local authority will not be a PCBU. *Note* – A person may be both a PCBU, within the meaning of section 5 of the WHS Act, and a worker within the meaning of section 7 of the WHS Act.
Place of safety	A place where workers can shelter in the case of an emergency where there is a respirable atmosphere and protection from the effects of fire.

Term	Description
Principal Contractor	Under the WHS Regulation, each construction project must have a Principal Contractor. There can only be one Principal Contractor for a construction project at any one time. A Principal Contractor is a person conducting a business or undertaking (PCBU). The PCBU who commissions a construction project is the Principal Contractor for that project, unless they engage another PCBU to be the Principal Contractor for the duration of the project. The PCBU who commissions the construction project must authorise the nominated Principal Contractor to have management or control of the workplace and discharge their duties as the Principal Contractor. A person with management or control of a workplace must comply with section 20 of the WHS Act.
Psychosocial hazard	A psychosocial hazard is a hazard that — (a) arises from, or relates to — i. the design or management of work, or ii. a work environment, or iii. plant at a workplace, or iv. workplace interactions or behaviours, and (b) may cause psychological harm, whether or not it may also cause physical harm.
Psychosocial risk	A risk to the health or safety of a worker or other person arising from a psychosocial hazard.
Reference design	For the purposes of this Code of practice, a reference design is a preliminary design prepared by or on behalf of the Client Organisation. It serves as a basis for tendering and provides sufficient detail to enable contractors to understand the scope, intent, and key requirements of the proposed tunnel construction works in sufficient detail to enable health and safety planning, provisioning and risk assessment.
Respirable	Particles or contaminants that are small enough to be inhaled deeply into the lungs, reaching the alveolar region where gas exchange occurs.
Risk	The possibility that harm (death, injury or illness) might occur when exposed to a hazard.
Risk register	A formalised record of Risks identified from a risk assessment process including details of risk sources (hazards) risk controls and risk owners. A Risk Register is the means of recording and monitoring the Risk Management process.
Safety Critical System	A system whose failure or malfunction may result in death or serious injury to people.

Term	Description
Serious injury or illness	An injury or illness requiring the person to have – (a) immediate treatment as an in-patient in a hospital, or (b) immediate treatment for — i. the amputation of any part of his or her body, or ii. a serious head injury, or iii. a serious eye injury, or iv. a serious burn, or v. the separation of his or her skin from an underlying tissue (such as degloving or scalping), or vi. a spinal injury, or vii. the loss of a bodily function, or viii. serious lacerations, or (c) medical treatment within 48 hours of exposure to a substance, and includes any other injury or illness prescribed by the regulations but does not include an illness or injury of a prescribed kind.
Shaft	A 'vertical or inclined way or opening, from the surface downwards or from any underground working, the dimensions of which (apart from the perimeter) are less than its depth'. For the purposes of this Code of practice, a shaft is a vertical or steeply inclined passage cut through the ground at an angle greater than 20 degrees from the horizontal.
Should	'Should' indicates a recommended course of action.
Similar Exposure Group (SEG)	SEGs are used to identify a group of workers who have the same general exposure to risks. This can include: • the similarity and frequency of the tasks performed, • the types of materials and processes used to complete tasks, • and/or the similarity of the way tasks are performed.
Tender	A response to a procurement process for design or construction services that is typically competitive in which suppliers or contractors submit proposals including a costed offer demonstrating how their resources, capabilities, and methodologies will meet the specified outcomes and requirements of a procuring entity. The tender submission should enable the client to evaluate and select the most suitable provider based on value, alignment with objectives, and compliance with procurement criteria including for example risk management.

Term	Description
Toxic gas	A gas that, when inhaled, can cause acute or chronic adverse health effects such as respiratory distress, poisoning, nerve damage, or other systemic harm. Toxic gases are classified as hazardous chemicals under the WHS Regulation and must be managed to prevent exposure above workplace exposure standards.
Trigger Action Response Plan (TARP)	An administrative control measure that documents risk management requirements and defines specific, pre-agreed actions workers must take when an operational or environmental condition crosses a specific threshold (trigger).
Tunnel	A tunnel is defined in the WHS Regulation as an underground passage or opening that is approximately horizontal and commences at the surface of the ground or at an excavation'. For the purposes of this Code of practice a tunnel includes all associated underground structures, including caverns, cut-and-cover tunnel excavations, portal structures and trenches, howsoever constructed that facilitate underground construction and that create health and safety risks from underground construction.
Unsupported ground	Unsupported ground refers to any area within an underground excavation where the natural ground has been exposed by excavation and has not yet been stabilised or supported by engineered ground support systems and/or has not been deemed safe for entry or occupation by a competent person.
Ventilation Officer	A Ventilation Officer (VO) is a designated specialist responsible for the implementation, monitoring, and maintenance of ventilation systems within tunnel construction environments. The VO ensures that air quality meets regulatory and safety standards, manages risks associated with airborne contaminants, and supports emergency response protocols. The role requires demonstrated competency in ventilation system design, change management, airflow and contaminant monitoring, confined space safety, and ensuring PCBU compliance with WHS legislation, including relevant codes of practice issued by SafeWork NSW. The VO should possess appropriate technical qualifications, practical experience, and maintain ongoing professional development to ensure safe and effective ventilation throughout all phases of tunnelling operations.
Verification activities	Verification activities: The process of checking the extent to which the performance requirements set for a risk control are being met in practice. Company safety and health management systems might use a variety of terms for "verification" activities. Common terms include audit, review, monitoring and active monitoring.
Vitiated air	Air that has been contaminated or depleted of oxygen due to the presence of harmful gases, dusts, fumes, or vapours, and is no longer suitable for safe breathing without ventilation or respiratory protection. Part of the atmosphere that must be continuously replaced by fresh air to maintain safe working conditions underground.
Volunteer association	A group of volunteers working together for one or more community purposes where none of the volunteers, whether alone or jointly with any other volunteers, employs any person to carry out work for the volunteer association.

Term	Description
Workplace Exposure Standards (WES)	The *Workplace Exposure Standards for Airborne Contaminants* published by Safe Work Australia, as in force or remade from time to time.
Work group	A group of workers established to facilitate the representation of workers by one or more health and safety representatives. A work group may be all workers at a workplace but it may also be appropriate to split a workplace into multiple work groups where workers share similar work conditions or are exposed to similar risks and hazards. For example, all workers on night shift.
Worker	Any person who carries out work for a PCBU including work as an employee, contractor or subcontractor (or their employee), self-employed person, outworker, apprentice or trainee, work experience student, employee of a labour hire company placed with a 'host employer' or a volunteer. *Note –* A person may be both a worker, within the meaning of section 7 of the WHS Act, and a PCBU within the meaning of section 5 of the WHS Act.
Workplace	Any place where work is carried out for a business or undertaking and includes any place where a worker goes, or is likely to be, while at work.

Appendix B - Relevant information and guidance

The following codes of practice, guidance materials, Australian/New Zealand and International Standards may be involved in tunnelling work and should be referred to.

SafeWork NSW codes of practice:

- Work health and safety consultation, cooperation and coordination
- How to manage work health and safety risks
- Safe design of structures
- Managing noise and preventing hearing loss at work
- Hazardous manual tasks
- Managing risks of hazardous chemicals in the workplace
- Worker accommodation
- Managing psychosocial hazards at work
- Construction work
- Formwork
- Moving plant on construction sites
- Managing electrical risks in the workplace
- Welding processes
- Confined space entry
- Managing the risks of plant in the workplace
- Worker accommodation
- Sexual and gender-based harassment
- Managing the risk of fatigue at work
- Managing risks of respirable crystalline silica in the workplace
- Managing the work environment and facilities
- Elevating work platforms

Other codes of practice:

- National Transport Commission*: Australian Code for the Transport of Dangerous Goods by Road & Rail*
- NSW Trade & Investment Mine Safety *Code of Practice: Inundation and inrush hazard management*
- *Australian Code for the Transport of Explosives by Road and Rail*
- International Tunnelling and Underground Space Association (ITA-AITES) and International Association of Engineering Insurers (IMIA) *Code of Practice for risk management of tunnel works*

Other guidance documents:

- Safe Work Australia's Guidance material: *Managing the risks of working in heat*
- SafeWork NSW Fact Sheet: *Work in hot environments*
- Safe Work Australia's Interpretive Guideline: *The meaning of 'reasonably practicable'*
- Safe Work Australia's *Principles of good work design: A work health and safety handbook*
- Safe Work Australia's Guide *Measuring and assessing workplace exposure to whole-body vibration*
- Safe Work Australia's Guide *Measuring and assessing workplace exposure to hand-arm vibration*
- Safe Work Australia's Guide *Managing risks of exposure to hand-arm vibration in workplaces*
- Safe Work Australia's *Workplace Exposure Standards for Airborne Contaminants*
- Safe Work Australia's *Hazardous Chemical Information System (HCIS)*
- Safe Work Australia's *Health monitoring guide for Crystalline Silica*
- Safe Work Australia's *Working with crystalline silica Guidance for PCBUs*
- NSW Resources Regulator's *Legislative obligation: health control plans – NSW mining and extractives industry* (Fact Sheet PUB18-36)
- NSW Resources Regulator – 2003 – *Guide – Managing risks of subsidence* – WHS (Mines and Petroleum Sites) Legislation
- NSW Resources Regulator: *TRG 3608: Non-metallic materials for use in underground coal mines and reclaim tunnels in coal mines*
- NSW Department of Planning and Environment's *Hydraulic Safety Mining design guideline – MDG 3007*
- NSW Resources Regulator (NSW Department of Primary Industries and Regional Development) TRG 41 Technical reference guide: *Fluid power safety systems at mines*
- Australian Energy Council – *Electric Arc Flash Hazard Management Guideline*
- Australian Tunnelling Society – *Ventilation during tunnel construction Industry Considerations. Air Quality Working Group Information Package – Part 7 of 12* (December 2018)
- CIRIA Report R185 *The Observational Method in ground engineering: principles and applications*
- International Tunnelling Association ITA Report No 36 / July 2025 TUST-D-24-02789R1 *WG 23 Design & construction of shafts*
- International Tunnelling Association ITA Report WG5 Health and Safety in Works - *Guidelines for Good Working Practice in High Pressure Compressed Air*
- International Tunnelling Association ITA Report No 010 – *Guidelines for Good Working Practice in High Pressure Compressed Air*
- Crossrail Best Practice Guide – *Construction Railways Operations*
- EU Physical Agents Directive (2002/44/EC)

Australian/New Zealand Standards:

- AS 1012 series – *Methods of testing concrete*
- AS 1170 series – *Structural design actions*
- AS 1210-2010 – *Pressure vessels*
- AS/NZS 1269.3:2005 – *Occupational noise management, Part 3: Hearing protector program*
- AS 1319-1994 – *Safety signs for the occupational environment*
- AS/NZS 1337.1:2010 – Personal eye protection – Eye and face protectors for occupational applications
- AS/NZS *1337.2:2012 – Personal eye protection – Mesh eye and face protectors for occupational applications*
- AS/NZS *1337.6:2012 – Personal eye protection – Prescription eye protectors against low and medium impact*
- AS 1345-1995 – *Identification of the contents of pipes, conduits and ducts*
- AS 1379-2007 – *Specification and supply of concrete*
- AS 1418.5-2013 – *Cranes, hoists and winches, Part 5: Mobile cranes*
- AS 1418.8-2008 – *Cranes, hoists and winches, Part 8: Special purpose appliances*
- AS/NZS 1530.3:1999 – *Methods for fire tests on building materials, components and structures, Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release*
- AS 1530.4:2014 – *Methods of fire tests on building materials, components and structures, Part 4: Fire resistance tests for elements of construction*
- AS/NZS 1576.1:2019 – *Scaffolding, Part 1: General requirements*
- AS 1657:2018 – *Fixed platforms, walkways, stairways and ladders – Design, construction and installation*
- AS/NZS 1680.1:2006 – *Interior and workplace lighting*
- AS/NZS 1715:2009 – *Selection, use and maintenance of respiratory protective equipment*
- AS/NZS 1716:2012 – *Respiratory protective devices*
- AS 1726:2017 – *Geotechnical site investigations*
- AS/NZS 1800:1998 – *Occupational protective helmets – Selection, care and use*
- AS/NZS 1801:2024 – *Occupational protective helmets*
- AS/NZS 2161.1:2016 – *Occupational protective gloves*
- AS 2187 – *Explosives*
- AS/NZS 2210.1:2025 – *Safety and occupational footwear*
- AS 2294.1-1997 series – *Earth-moving machinery – Protective structures*
- AS 2294.1-1997 – *Earth-moving machinery – Protective structures – Part 1: General*
- AS/NZS ISO 23875:2023 – *Mining – Air quality control systems for operator enclosures – Performance requirements and test methods*
- AS 2550 series – *Cranes, hoists and winches – Safe use*
- AS 2550.1-2011 – *Cranes, hoists and winches – Safe use, Part 1: General requirements*
- AS 2550.5:2016 – *Cranes, hoists and winches – Safe use, Part 5: Mobile cranes*
- AS 2550.15:2019 – *Cranes, hoists and winches –Safe use, Part 15: Concrete placing equipment*
- AS/NZS 2566.1:1998 – *Buried flexible pipelines*

- AS 2670.1-2001 – *Evaluation of human exposure to whole-body vibration, Part 1: General requirements*
- AS/NZS 3000:2018 – *Electrical installations (known as the Australian/New Zealand Wiring Rules)*
- AS/NZS 3012:2019 – *Electrical installations – Construction and demolition sites*
- AS 3610.1:2018 – *Formwork for concrete*
- AS/NZS 3760:2022 – *In-service safety inspection and testing of electrical equipment and RCDs*
- AS/NZS 4024.1:2019 Series – *Safety of machinery*
- AS/NZS 4024.1601:2024 - *Safety of machinery – Part 1601: Guards – General requirements for the design and construction of fixed and movable guards*
- AS/NZS 4024.1801:2025 – *Safety of machinery – Part 1801: Safety distances to prevent danger zones being reached by upper and lower limbs*
- AS/NZS 4024.2201:2024 - *Safety of machinery - Permanent means of access to machinery - (Part 1): Choice of fixed means and general requirements of access*
- AS/NZS 4024.2202:2024 – *Safety of machinery – Permanent means of access to machinery - (Part 2): Working platforms and walkways*
- AS/NZS 4024.2203:2024 - *Safety of machinery - Permanent means of access to machinery - (Part 3): Stairs, stepladders and guard rails*
- AS/NZS 4024.2204:2024 - *Safety of machinery - Permanent means of access to machinery - (Part 4) Fixed ladders*
- AS/NZS 4024.3611:2015 – *Safety of machinery – Part 3611: Conveyors – Belt conveyors for bulk materials handling*
- AS 4041-2006 – *Pressure piping*
- AS 4326-2008 – *The storage and handling of oxidizing agents*
- AS/ NZS 4602.1:2024 - *High visibility safety garments – Garments for high risk applications*
- AS 4774.*1:2026 – Work in compressed air and hyperbaric facilities – Part 1: Work in tunnels, shafts and caissons*
- AS/NZS 4836:2023 – *Safe working on or near low-voltage and extra-low voltage electrical installations and equipment*
- AS 4994.1:2023 – *Temporary edge protection*
- AS ISO 5349.1-2013 – *Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration*
- AS/NZS 60079 series – *Explosive atmospheres*
- AS/NZS 60335.2.69:2017 – *Household and similar electrical appliances – Safety*
- AS ISO 3449:2020 – *Earth-moving machinery – FOPS – Laboratory tests and performance requirements*
- AS ISO 3471:2020 – *Earth-moving machinery – Roll-over protective structures – Laboratory tests and performance requirements*
- AS ISO 12117:2020 – *Earth moving machinery – Tip-over protection structure (TOPS) for compact excavators – Laboratory tests and performance requirements*
- *AS ISO 13766: Earth-moving and building construction machinery - Electromagnetic compatibility (EMC) of machines with internal electrical power supply*
- AS *60529:2025 - Degrees of protection provided by enclosures (IP Code)* (IEC 60529:1989 (ED. 2.2) MOD)

International Standards

- ISO 13849-1:2023 - *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*
- ISO 17409:2020 - *Electrically propelled road vehicles – Conductive power transfer – Safety requirements*
- IEC 61000 series – *Electromagnetic compatibility (EMC)*
- IEC 62485-6 – *Safety requirements for secondary batteries and battery installations – Part 6: Safe operation of lithium-ion batteries in traction applications*
- IEC 62619 - *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*
- IEC 62281 - *Safety of primary and secondary lithium cells and batteries during transport*

Other Standards

- UN 38.3 - *Recommendations on the Transport of Dangerous Goods: UN Manual of Tests and Criteria*
- EN 689:2018+AC:2019 *Workplace exposure – Measurement of exposure by inhalation to chemical agents – Strategy for testing compliance with occupational exposure limit values*
- BS EN 1997-1:2024 Eurocode 7 – *Geotechnical Design – Part 1: General Rules*, Institution of Civil Engineers (ICE) Guidance on Observational Method, British Standards Institution (BSI) Commentary on Eurocode 7
- EN 1366 – *Fire resistance tests for service installations*
- EN 14253:2003 – *Mechanical vibration – Measurement and calculation of occupational exposure to whole-body vibration with reference to health – Practical guidance*
- BS EN 16191 *Tunnelling machinery - Safety requirements*
- BS 6164 – *Health and safety in tunnelling in the construction industry*

Appendix C - Airborne Contaminants

Contaminant	Buoyancy	Comment/Origin
Acetylene (C2H2)	Positive	Compressed gas cylinder leak
Ammonia (NH3)	Positive	From concreting or grouting leak from refrigeration equipment
Asbestos	Negative	Thermal lagging, old pipes, building materials (demolition or renovation)
Butane (C4H10)	Negative	Compressed gas cylinder leak
Carbon Dioxide (CO2)	Negative	Initially buoyant if a hot product of combustion
Carbon Monoxide (CO)	Neutral	Incomplete combustion of diesel fuel
Hydrogen Sulphide (H2S)	Negative	Decomposition of organic matter
Methane (CH4),	Positive	Natural ground contaminant, or from compressed gas leak
Nitric Oxide	Neutral	Produced by explosives and engines
Nitrogen Dioxide (NO2)	Negative	Produced by electric arc welding and from NO in atmosphere
Oxygen depletion	Neutral	Oxygen may be consumed or displaced
Oxygen enrichment	Neutral	Enhanced risk of ignition and fire. Due to compressed gas cylinder leak
Ozone (O3)	Negative	From electric arc welding
Propane	Negative	Fire and explosion hazard
Respirable Silica	Negative	Concrete, shotcrete, ground, cement
Sulphur Dioxide (SO_2)	Negative	Bacterial activity, blasting, diesel combustion
Diesel Particulate Matter (DPM)	Negative	Fine particles of elemental carbon with adsorbed organics (e.g., PAHs); emitted from diesel engines
Polycyclic Aromatic Hydrocarbons (PAHs)	Negative	Carcinogenic organics adsorbed onto DPM
Volatile Organic Compounds (VOCs)	Negative	Includes benzene, formaldehyde, and others
Metals (e.g., nickel, chromium)	Negative	Engine wear and fuel/lubricant additives

Appendix D - Respirable Crystalline Silica (RCS)

Status and purpose of this appendix

This appendix forms part of the guidance material supporting Chapter 19 of this Code of practice. The control measures listed are examples provided to assist duty holders in identifying and selecting reasonably practicable controls for managing risks associated with RCS during tunnelling and shaft construction.

Example Control Measure
Extraction ventilation positioned adjacent to the source and designed to effectively capture airborne dust where workers are located
Use of brattices to assist ventilation extraction system efficiency
Enclosed cabins on mobile plant with filtration systems and positive pressurisation against contaminants
HEPA filtration in control rooms and crib rooms underground
Interlock systems on cabin doors of mined tunnelling equipment that stop cutting if the cabin becomes unsealed
Fixed dust suppression sprays on conveyor belt systems
Conveyor wash boxes to remove residual dust and debris
Misting water spray to minimise dust disturbance from traffic
Heavy plant attachments fitted with fixed dust suppression (e.g. hammers, excavators)
Use of validated local exhaust ventilation (LEV) systems fitted to tunnel trenching or cutting machines
Dedicated dust suppression or extraction ventilation systems for hand-held cutting tools
Water misting systems used during jackhammering
Use of water carts for dust suppression in tunnels, roadways and stockpile areas
Spray application of polymer or sealant to stabilise potentially dusty surfaces
Real-time monitoring to assess the effectiveness of control measures and identify areas requiring additional controls
Heavy plant operators to allow sufficient time for airborne dust to clear before exiting enclosed cabins
Work planning to minimise the number of workers exposed
Worker rotation to reduce exposure duration
Rescheduling proximal crews to avoid secondary exposures
Prohibition of dry sweeping or compressed air cleaning; use HEPA vacuum or wet methods instead
Periodic washing of plant, machinery and surfaces
Boot storage areas to prevent transfer of RCS-contaminated mud
Provision of boot washing facilities
Regular wet cleaning of heavy plant cabins
Health monitoring for workers at significant risk of crystalline silica exposure

Example Control Measure
Personal exposure monitoring for RCS at a frequency determined by risk
Signage at hazardous work areas indicating required PPE
Training on RCS risks and control measures
Clean-shaven policy for users of tight-fitting respiratory protection
Fit testing for all users of tight-fitting respiratory protection
Respiratory protection providing a minimum protection factor of 50, unless a risk assessment determines otherwise
Cleaning air filters from heavy plant/equipment inside a purpose-built extraction unit with a closed-loop collection process

Appendix E - Similar Exposure Groups (SEGS)

Status and use of this appendix

This appendix provides example Similar Exposure Groups (SEGs) commonly encountered in tunnel and shaft construction activities. It is intended to support risk assessment, exposure monitoring, and health monitoring processes by assisting PCBUs to group workers with similar exposure profiles.

The SEGs listed are indicative only and are not exhaustive. Actual exposure profiles may vary depending on the nature of the task, work methods, materials, controls in place, and the stage of construction or operation. PCBUs should determine SEGs based on site-specific assessment and should review and update them as work activities change.

Inclusion of a role in this appendix does not imply a uniform level of risk, nor does exclusion imply the absence of risk.

Above ground workers

SEG	Location	Generalised description
Carousel personnel	Precast	Persons involved in the operational activities associated with manufacture of precast concrete segments on the carousel lines.
Cleaner	Precast, general site	Persons involved in cleaning site offices, crib rooms, and laundry.
Crane operations	Precast, general site	Persons who operate crawler or mobile cranes or perform dogger or rigger duties.
Form, reo, pour	Precast, general site	Formworkers, steelfixers, and concreters involved in form, reo or pour activities.
Gantry crane operator	Precast, spoil shed	Operation of an overhead crane for the purpose of lifting heavy loads of materials.
General labourer	Precast, general site, spoil shed	Persons on-foot conducting a range of tasks including spotting, jackhammering, or using hand-held tools.
Ground support	General site	Persons involved in ground support works including piling, drilling, mesh installation and shotcrete.
Heavy plant operators	Precast, spoil shed, general site	Operators of heavy plant such as loaders, excavators, bobcat etc.
Management and professional services	Precast, general site	Client representatives, engineers, Occupational Hygienists, laboratory technicians, archaeologists or other consultants.
Other surface workers	Precast, general site	Other personnel not otherwise classified, including scaffolders and light plant operators, store persons and warehouse operations.
Processing facility	Precast, general site	Persons who work or operate the batch plant, grout plant, slurry plant or water treatment plants.
Supervisors and surveyors	Precast, spoil shed, general site	Includes area supervisors, foreman or leading hands as well as persons nominated as a surveyor.

SEG	Location	Generalised description
Trades services	Precast, spoil shed, general site	Trades including electricians, fitters, boilermakers, carpenters, plumbers or those otherwise classified as maintenance workers.
Traffic control	General site	

Underground workers

SEG	Location	Generalised description
Crane operations	Cut and cover	Persons who operate crawler or mobile cranes or perform dogger or rigger duties.
Form, reo, pour	Mined tunnelling, cut and cover, TBM tunnelling	Formworkers, steelfixers, and concreters involved in form, reo, pour activities.
Ground support	Cut and cover, drill and blast, mined tunnelling	Persons involved in ground support works including piling, drilling, mesh installation and shotcrete.
Heavy plant operators	Cut and cover, drill and blast, mined tunnelling, TBM tunnelling	Operators of heavy plant such as articulated haul trucks, excavators, dozers, etc.
Management & professional services	Precast, tunnel site(s), workshop	Client representatives, engineers, Occupational Hygienists, geotechnical or other consultants.
Profiler, surface miner operators	Mined tunnelling	Operators of other mined-tunnelling equipment including excavators, profilers or surface miners, being medium or large size plant for the excavation of hard surfaces.
Roadheader operators	Mined tunnelling	Operators of roadheaders. Further categorised into those with or without enclosed cabins.
Supervisors and surveyors	Cut and cover, drill and blast, mined tunnelling, TBM tunnelling	Includes area supervisors, foreman or leading hands as well as persons nominated as a surveyor.
TBM operators	TBM tunnelling	Persons who are primarily stationed on, and operate, the TBM from within a cabin.
TBM ring builders	TBM tunnelling	Persons who are primarily stationed on, and work at the front of the TBM building the rings.
TBM backend	TBM tunnelling	Persons who are primarily stationed on, and work on the TBM including those who extend services and conveyors, handle segments and perform grouting activities.

SEG	Location	Generalised description
Trades services	Cut and cover, mined tunnelling, TBM tunnelling	Trades including electricians, fitters, boilermakers, carpenters, or otherwise classified as maintenance workers.
Tunnellers	Drill and blast, mined tunnelling, TBM tunnelling	Persons on-foot in tunnels under construction conducting a range of tasks.
Traffic Controllers, ancillary maintenance and cleaning labour	As required underground	Persons on-foot in tunnels under construction conducting a range of tasks.
Waterproofing	Cut and cover, mined tunnelling	Personnel involved in activities associated with waterproofing.

Appendix F - Use of Observational Methods (OM)

Overview

This appendix does not mandate or endorse the use of the Observational Method. It is provided to clarify the distinction between formal OM and routine monitoring and verification practices used in contemporary tunnelling methods such as SCL/SEM.

The term 'observational method' is largely attributed to Peck (1969)[18] largely based on US experiences in 'soft ground'. The approach was later refined by Nicholson (1999)[19] reflecting experience within the UK also in clay soils.

Peck's original method was based on several core principles:

- Availability of sufficient site investigation to establish the general nature and properties of the ground.
- Establishment of a design for both the most probable and the most unfavourable ground conditions.

To quote the HSE investigation into the safety of observational methods (OM) (1996)[20]:

- "The 'observational method' is a process in which a pre-determined design is reviewed during construction... Design review is a process of critical examination of product performance; review is not a process for design modification as work proceeds."

The collapse of NATM tunnels at Heathrow in 1994 prompted this investigation and the HSE found that the observational method had not been consistently or correctly applied. Key failings included insufficient monitoring, poor documentation, lack of contingency planning, and a weak design–construction interface that lead to miscommunication and escalating risk. The investigation also identified inadequate ground investigation, over-reliance on deformation monitoring without robust baseline predictions, and a lack of competence and training in OM principles.

The HSE recommended a risk-based approach to tunnelling, improved collaboration between designers and constructors, enhanced monitoring systems, robust emergency procedures, and stronger quality assurance. It also called for greater emphasis on buildability, risk management, and clear design accountability.

Nicholson's work developed Pecks concepts, emphasising:

- Starting with a design based on the most probable ground conditions.
- Establishing predicted behaviours, trigger values, and contingency plans.
- Using monitoring to verify predictions and adjusting the design only if actual behaviour deviates.

He also identified four key requirements for successful application:

- Define acceptable limits of behaviour.
- Assess the range of possible behaviours.
- Plan monitoring to detect deviations early.
- Prepare contingency actions in advance.

18 Peck R.B, Deep Excavation and Tunnelling in Soft Ground, 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, (1969)

19 Nicholson, D. (1999). The Observational Method in Ground Engineering: Principles and Applications. CIRIA Report C185, Construction Industry Research and Information Association (CIRIA), London.

20 Health and Safety Executive (1996). Safety of New Austrian Tunnelling Method (NATM) Tunnels: A Review of Sprayed Concrete Lined Tunnels with Particular Reference to London Clay. HSE Books, ISBN: 978 0 7176 1068 6.

The ITA/IMIA *Code of practice for risk management of tunnels works* (2023) written with the objective of securing best practice for risk management states:

> Where an 'observational method' is proposed or required, there shall be compliance with the requirements of CIRIA Report R185 or an equivalent standard. In particular, where the design is
>
> based on or includes any element of an 'observational' approach for its implementation during the Construction Stage, the Insured shall ensure that the Designer has in place, prior to the commencement of the Construction Stage, pre-planned and pre-designed Controls.

The use of the observational method continues to be contentious many years after Peck's publication in 1969. CIRIA is currently undertaking another revision.

To summarise, monitoring and review are essential tools for validating design assumptions when adopting OM, but they should not be used as a substitute for proper design development or to justify ad hoc design changes during construction.

Any modifications should occur within a structured framework of predefined trigger levels and contingency plans. An observational method requires the design to define limits of acceptable behaviour for the ground and support system. There should be a pre-planned "way out" that can be implemented quickly and effectively to prevent instability, so far as is reasonably practicable.

The design should assess the sequence of construction and the stability of the excavation, and include contingency measures based on the range of conditions and behaviours that may be encountered.[21]

The successful use of observational methods depends on effective communication and collaboration across the project team, with clearly defined roles and responsibilities.

Powderham et al[22] state in Chapter 1 'The art of achieving agreement'

> *Achieving agreement can present a substantial challenge. The OM demands commitment by all stakeholders and is fundamental to ensuring success in any application. Consequently, when there is no overriding driver for change, there is typically little incentive to depart from convention or 'business as usual'. The parties are inclined to remain within their respective comfort zones.*
>
> *Even with a crisis as a catalyst, it often takes sustained and convincing advocacy by the proposer to secure the 'buy-in' by the other parties. They will probably be in varying degrees of disagreement and will therefore not readily reach a consensus that the OM does indeed offer the best way forward.*

Other considerations

Eurocode 7 (EN 1997-1)[23] outlines conditions where OM application may not be the best approach. A PCBU should carefully consider the following issues regarding the use of OM on their projects

- Ground conditions are well known and predictable:
  If geotechnical behaviour can be reliably predicted through calculations or prescriptive measures, the observational method may introduce unnecessary complexity.
- Monitoring capabilities:
  The method relies on real-time monitoring of parameters such as displacement, pore pressure, stress and/or strain. If the instrumentation to monitor critical parameters and the system responses cannot be reliably installed or maintained, the method should not be used.

21 Refer for example Guideline for the Geotechnical Design of Underground Structures with Conventional Excavation Austrian Society for Geomechanics (2010)

22 The Observational Method in Civil Engineering Minimising Risk, Maximising Value Alan Powderham and Tony O'Brien CRC Press 2020

23 For further reference refer BS EN 1997-1:2024 Eurocode 7 – Geotechnical Design – Part 1: General Rules, Institution of Civil Engineers (ICE) Guidance on Observational Method, British Standards Institution (BSI) Commentary on Eurocode 7.

- Clear definition of acceptability limits:
  Limits of acceptable behaviour should be defined before construction begins. If these cannot be established, the method is unsuitable.
- Implementation of contingencies to prevent failure:
  The method requires pre-planned contingency measures to meet safety requirements.
- Construction schedules:
  There should be sufficient time for iterative adjustments to supports and sequencing based on monitoring results.
- Lack of competence:
  The method demands experienced and competent engineers capable of interpreting monitoring data and making timely decisions.

Appendix G - TBM Hazard Prompt Table

Purpose and status of this appendix

This appendix provides a hazard prompt table to support hazard identification and risk assessment for tunnel boring machine (TBM) operations. The table is not exhaustive and is intended to assist designers, PCBUs and project teams in systematically considering hazards that may arise during TBM launch, operation, maintenance and retrieval.

The relevance of any hazard and the selection of appropriate control measures should be determined through project-specific risk assessment, having regard to the nature of the work and what is reasonably practicable.

Hazard category	Hazard description
Mechanical / Operational	Failure of TBM thrust or steering systems
Mechanical / Operational	Hydraulic system failure
Mechanical / Operational	Power supply failure
Mechanical / Operational	Damage to segments or gaskets
Mechanical / Operational	Loss of effectiveness of seals at the back of the TBM
Mechanical / Operational	Flotation under shallow cover
Mechanical / Operational	Over-excavation leading to face collapse, particularly during TBM launch and receival
Mechanical / Operational	Inability to close earth pressure balance screw conveyor leading to inundation
Geotechnical	Ground heave or settlement beyond design predictions
Geotechnical	TBM entrapment in boulders or hard inclusions
Geotechnical	Unanticipated voids, fault zones or zones of weakness resulting in inundation
Geotechnical	Excessive wear or damage to the cutterhead requiring intervention from surface
Geotechnical	Breakouts from the segmental lining
Geotechnical	Geological materials and airborne contaminants, including respirable crystalline silica and naturally occurring asbestiform minerals
Geotechnical	Unexpected ground chemistry
Water / Pressure	Hyperbaric working risks
Water / Pressure	Failure of bulkheads or pressure
Fire / Explosion / Contamination	Fire in TBM electrical or hydraulic systems
Fire / Explosion / Contamination	Explosion risk from methane or other flammable gases
Human factors	Operator error in pressure control, steering or machine attitude
Human factors	Inadequate communication between TBM operations and surface
Human factors	Fatigue, workload or cognitive overload

Notes on use

Hazards may arise concurrently and interact with one another.

Additional hazards may be identified depending on TBM type (e.g. EPB, slurry), geology, depth and project configuration.

This table should be used in conjunction with relevant chapters of this Code, including those addressing ground conditions and support, ventilation, fire and emergency management.

Appendix H - Examples of control measures for Diesel Engine Exhaust (DEE)

Purpose and status of this appendix

This appendix provides non-exhaustive examples of control measures that may be considered when managing exposure to DEE and diesel particulate matter (DPM) in underground construction. The appropriateness of any control will depend on the nature of the work, the level of risk, and what is reasonably practicable in the circumstances.

This appendix should be read in conjunction with Chapter 18 Diesel plant – emissions management.

Example control measure
Use of electrically powered or alternative low-emission plant where reasonably practicable. Designing work methods to avoid or reduce the need for diesel plant underground.
Substituting high-emission plant with lower-emission engines or alternative equipment. Use of conveyors or fixed systems in place of mobile diesel plant where practicable.
Remote or tele-operated plant to separate workers from diesel exhaust sources. Physical separation of diesel plant routes from pedestrian work areas.
Selection of low-emission engines compliant with recognised emission standards. Exhaust after-treatment systems such as diesel particulate filters (DPFs) and oxidation catalysts. Emission-based maintenance, including monitoring of back pressure and exhaust parameters. Adequate ventilation designed to dilute and remove diesel exhaust consistent with installed plant power and duty cycles. Fuel quality controls, including use of low-sulphur diesel and contamination prevention. Real-time or continuous monitoring systems to detect elevated DPM or related exhaust gases where required.
Scheduling and sequencing work to limit concurrent diesel plant operation. Idling management and shut-down procedures for diesel plant. Maintenance programs informed by baseline emissions testing. Training for operators and maintenance personnel on emission reduction practices. Trigger Action Response Plans (TARPs) for elevated DEE and DPM levels or loss of ventilation effectiveness.
Respiratory protective equipment (RPE) used only where higher-order controls do not sufficiently control exposure, and selected, fitted and maintained in accordance with applicable standards. PPE should not be relied upon as the primary control for DEE and DPM exposure.

Notes on application

Not all controls will be appropriate or necessary for every underground construction activity. Controls should be selected based on risk assessment, monitoring data and review of control effectiveness.

Multiple controls may be required in combination to adequately manage DEE and DPM exposure.

This appendix does not replace the requirement to comply with the WHS Act and Regulation or Chapter 18 of this Code.

Disclaimer

This publication may contain information about the regulation and enforcement of work health and safety in NSW. It may include some of your obligations under some of the legislation that SafeWork NSW administers. To ensure you comply with your legal obligations you must refer to the appropriate legislation.

Information on the latest laws can be checked by visiting the NSW legislation website www.legislation.nsw.gov.au

This publication does not represent a comprehensive statement of the law as it applies to particular problems or to individuals or as a substitute for legal advice. You should seek independent legal advice if you need assistance on the application of the law to your situation.

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