Tunnelling

Code of Practice 2007

Workplace Health and Safety Queensland
Department of Justice and Attorney-General

Queensland Government

Important information about this code

The following provides information regarding the commencement, variations and transitional arrangements relevant to this code of practice.

This Queensland code of practice was preserved as a code of practice under section 284 of the *Work Health and Safety Act 2011*.

This code was varied by the Minister for Education and Industrial Relations on 21 December 2011 and published in the Queensland Government Gazette on 23 December 2011.

This preserved code commences on 1 January 2012.

The variations in this code detailed in the Work Health and Safety Variation of Codes of Practice Notice (No. 3) 2011 commence on 31 March 2012, except for the variation of section 2.2.7.8 that commences 1 July 2012.

For the period 1 January 2012 to 30 June 2012 inclusive the applicable guidance for section 2.2.7.8 is the following guidance as provided in the Tunnelling code of practice 2007 at 31 January 2011:

2.2.7.8 Emergency response

A PCBU should ensure that, in the event of an emergency at a project, arrangements have been made for:

(a) the safe and rapid evacuation of people from the workplace
(b) emergency communications, and
(c) appropriate medical treatment of injured people.

Details of any evacuation arrangements should be kept on display in an appropriate location(s) at the workplace.

Types of emergencies considered should include:

- treatment and evacuation of a seriously injured person
- fire underground (e.g. fire on a tunnel-boring machine (TBM) or a truck)
- sudden flooding (e.g. inrush from an underground water feature)
- underground explosion (e.g. methane ignition)
- tunnel collapse, resulting in people being trapped
- power failure, and
- above ground emergency that compromises tunnel safety (e.g. fire or chemical spill).

The following emergency response control measures should be implemented:

- providing a system to identify who is underground (e.g. a tag board)
- developing site emergency procedures appropriate for the level of risk, including establishing an emergency assembly area and a plan for contacting, and subsequently interacting with emergency services
- providing emergency response equipment and training in how to use it
- providing control measures to reduce the severity of the emergency (e.g. self-closing bulkheads to control water inrush)
- providing fire suppression on vehicles, and

- providing self-rescuers, breathing apparatus and sealable, self-contained atmosphere refuges as well as instruction and practice in how to use the equipment.

Risk assessments determine if special emergency provisions, such as emergency rescue cages and means to extract people from difficult locations (e.g. from the base of a shaft or heading of a tunnel), are needed.

Traffic management rules should be implemented to ensure vehicles and mobile plant park in a way that prevents potential runaway and enables clear access at all times.

A close working relationship with local emergency services should be encouraged. For example, ask the emergency services to visit the tunnel site for site layout, access and emergency procedures.

Note: Special consideration should be given to the safe transport of injured people.

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Contents

1. Introduction

This *Tunnelling Code of Practice* is an approved code of practice under section 274 of the *Work Health and Safety Act 2011* (the Act).

An approved code of practice is a practical guide to achieving the standards of health, safety and welfare required under the Act and the *Work Health and Safety Regulation 2011* (the Regulation).

A code of practice applies to anyone who has a duty of care in the circumstances described in the code. In most cases, following an approved code of practice would achieve compliance with the health and safety duties in the Act, in relation to the subject matter of the code. Like regulations, codes of practice deal with particular issues and do not cover all hazards or risks which may arise. 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 Act and Regulation. Courts may regard a code of practice as evidence of what is known about a hazard, risk or control and may rely on the code in determining what is reasonably practicable in the circumstances to which the code relates.

Compliance with the Act and Regulation may be achieved by following another method, such as a technical or an industry standard, if it provides an equivalent or higher standard of work health and safety than the code.

An inspector may refer to an approved code of practice when issuing an improvement or prohibition notice.

How is the code organised

In providing guidance, the word ‘should’ is used in this Code to indicate a recommended course of action, while ‘may’ is used to indicate an optional course of action.

This Code also includes various references to provisions of the Act and Regulation which set out the legal requirements. These references are not exhaustive. The words ‘must’, ‘requires’ or ‘mandatory’ indicate that a legal requirement exists and must be complied with.

Who has duties?

A **person conducting a business or undertaking (PCBU)** has the primary duty under the Act to ensure, as far as reasonably practicable, that workers and other persons are not exposed to health and safety risks arising from the business or undertaking.

Officers, such as company directors, have a duty to exercise due diligence to ensure that the business or undertaking complies with the Act and Regulation. This includes taking reasonable steps to ensure that the business or undertaking has and uses appropriate resources and processes to provide and maintain a safe work environment.

Workers have a duty to take reasonable care for their own health and safety and that they do not adversely affect the health and safety of other persons. Workers must comply with any reasonable instruction and cooperate with any reasonable policy or procedure relating to health and safety at the workplace.

Consulting workers
Consultation involves sharing of information, giving workers a reasonable opportunity to express views and taking those views into account before making decisions on health and safety matters.

The Act requires that you consult, so far as is reasonably practicable, with workers who carry out work for you who are (or are likely to be) directly affected by a work health and safety matter.

If the workers are represented by a health and safety representative, the consultation must involve that representative.

You must consult your workers when proposing any changes to the work that may affect their health and safety.

Consulting, cooperating and coordinating activities with other duty holders
The Act requires that you consult, cooperate and coordinate activities with all other persons who have a work health or safety duty in relation to the same matter, so far as is reasonably practicable.

Sometimes you may share responsibility for a health and safety matter with other business operators who are involved in the same activities or who share the same workplace. In these situations, you should exchange information to find out who is doing what and work together in a cooperative and coordinated way so that all risks are eliminated or minimised as far as reasonably practicable.

Further guidance on consultation is available in the *Work Health and Safety Consultation, Coordination and Cooperation Code of Practice.*

1.1 Application and scope of code

Tunnelling, separate to mining, is a small industry with high risks that need to be managed. This code of practice provides practical guidance to safe tunnel construction and applies to the construction of underground tunnels, shafts, and passageways. It also applies to cut-and-cover excavations, both those physically connected to ongoing underground construction tunnels and those cut-and-cover operations that create conditions characteristic of underground construction.

The purpose of this code is to provide a health and safety framework, including technical criteria and guidance, to help plan the tunnel construction. The code gives health and safety guidance with specific requirements to assist in achieving compliance with the Act, the regulation and subordinate health and safety legislation.
These requirements include:

- geological and geotechnical exploration requirements
- construction work relating to tunnels and shafts
- tunnel design considerations
- geo-mechanical analysis
- design of tunnel linings, and

- instrumentation and monitoring during the construction and fit out phase of tunnel construction.

Health and safety issues covered in this code will provide PCBUs the flexibility to select from a variety of appropriate and effective methods to manage and control workplace hazards in tunnelling construction.
Specific tunnelling hazards that must be eliminated or minimised include:

reduced natural ventilation and light
difficult and limited access and egress
exposure to airborne contaminants
fire
explosion.

Note: Managing hazards and risks is paramount to the aim of this code '*Nobody works under unsupported ground'*, or when this is not possible, control measures are implemented to avoid ground falling on people (e.g. provide adequate fall protection – FOPS).

The code outlines a systematic plan of how to manage health and safety by integrating risk management and consultation into all activities that may have health and safety implications.

1.2 How is the code organised

The code is set out to identify and address specific hazards and associated risks. The sequence of hazards is not in any order of risk magnitude or preference. All the outlined issues are of major importance and all have a requirement in this code to be assessed and individually prioritised in order of high risk to low risk.

This code may contain terms that are specific to the construction of tunnels. These terms and others are defined in Appendix 3: Dictionary of defined terms.

2. Planning and preparation

2.1 A systematic approach to managing risks in underground construction

2.1.1 Overview

The *Work Health and Safety Act 2011* (the Act) and the *Work Health and Safety Regulation 2011* (the regulation) place responsibilities on a number of duty holders to ensure workplace health and safety.

The responsibilities of particular duty holders involved in tunnel construction work, the application of risk management principles and requirements for consultation are outlined in section 2.1.2 - Responsibilities of PCBUs.

The way to systematically plan and manage health and safety in the workplace is to integrate risk management and consultation into all those activities that may have health and safety implications. This will include activities such as purchasing, work methods or procedures, using contractors, reporting health and safety problems, investigating incidents and planning emergency procedures.

The provisions of this code should be considered during the tendering phase, as well as the planning and preparation stages for carrying out the tunnelling work. This code does not directly outline regulatory requirements from the regulation, but makes health and safety recommendations that may need to be factored into these processes.

This code makes reference to parts and sections of the Queensland legislation, where appropriate, as well as making reference to Australian Standards.

Duty holders must also be aware of other workplace health and safety legislative requirements that apply to safe tunnelling work, such as confined spaces, hazardous chemicals.

2.1.2 Responsibilities of PCBUs

2.1.2.1 Design stage

The PCBU's responsibilities under the Act depend on their role in the tunnel design and construction. PCBUs are in a key position to influence the safe construction of the project, as they usually develop the concept design for the tunnel and engage others to undertake the tunnel construction. Setting realistic timeframes for tendering, planning and project execution should also be considered at this stage.

Many aspects in tunnel design that influence the safe construction of a tunnel, such as the need to tunnel in rock or soft ground, are set in place in the concept design stage. The PCBU should consider how to safely construct and maintain the tunnel at this stage, to help reduce construction and ongoing operational and maintenance risks.

However, the PCBU is not always aware of all the complexities, such as the range of construction techniques, ground conditions and their effect on safety. It is therefore appropriate for the PCBU to consult with others at an early stage to take advantage of the opportunity to identify the best concept design. It also allows for a better understanding of the extent of the geotechnical investigation required, estimate of likely time needed to prepare a tender offer, construction time and areas of potential delay.

The PCBU must ensure that workplace health and safety plans are implemented during construction to ensure that safe working practices are in place. It would be appropriate for the PCBU to include this requirement, and specifically reference this code in contract documents.

2.1.2.2 Designers

Designers should ensure that:
- To the extent that they have control over a particular section of design work, the structure (or plant) can be safely erected, used, repaired, cleaned, maintained and demolished (life cycle), so that the health and safety of any person is not put at risk by the design.
- Information is provided to the client about the health and safety aspects of the design.

Designers should also ensure that hazards associated with the following are identified before commencing construction work:
- the design of the structure (permanent or temporary)
- systems of work required to erect, repair, clean and maintain the structure
- the intended use of the structure

- materials needed in the construction of the structure, and
- the demolition and life cycle of the structure.

Where there is more than one designer, critical aspects of the project should be documented and consultation carried out between all the designers, to ensure the safe integration of all the different design aspects in the work. When risks remain in the design work, information should be included with the design information to alert others to the risks.

The designer should document the assumed geotechnical conditions used in their design to enable exposed conditions to be compared against the design assumptions as the tunnelling progresses. This allows for monitoring of the conditions and a reassessment of the design, where the geotechnical conditions differ from that assumed in the design. This applies to plant likely to be affected by such a change, as well as the tunnel and associated ground support systems.

2.1.2.3 Principal contractors

The principal contractor, whether as a PCBU or as the person in control of the workplace, must provide and maintain a workplace that is safe and without risks to health and safety for their workers and other people present at the workplace or affected by the work. To fulfil these duties, the principal contractor must plan for the work to be done safely. The principal contractor must ensure that a site-specific WHS Management Plan is prepared and documented for the project before work commences.

The plan must include written safe work method statements, provided by the PCBUs, for all high risk construction activities. It should include the following details:

- arrangements for health and safety induction training
- arrangements for managing workplace incidents
- clear and effective ways for people to report hazards to their PCBU
- site safety rules and arrangements for informing people affected, and
- details where people have specific site health and safety responsibilities.

The plan must be monitored to ensure the work is being done safely according to the plan, and that it is effective. The plan must be kept up-to-date during the course of the construction work and made readily available for inspection to:

- anyone working, or about to commence work at the site
- members of the workplace health and safety committee
- elected workplace health and safety representatives.

The PCBU doing the work must provide and maintain a workplace that is safe and without risks to health and safety for themselves, their workers and others about matters over which they have control.

When contracting work out, the PCBU must ensure that contractors are planning and carrying out work safely and according to the requirements of the Act, the Regulation and this code of practice.

2.1.2.4 Persons conducting a business or undertaking (a PCBU)

In addition to consultation with the principal contractor in the overall job planning, each PCBU must develop written safe work method statements for high risk construction activities.

A PCBU must not allow a worker to carry out construction work unless the worker has completed the required induction training.

2.1.2.5 Workers

Workers should be encouraged to notify their PCBUs of health and safety hazards, risks and incidents. These notification practices should be outlined in the PCBU's policies, procedures and safety-related instructions.

2.1.2.6 Coordination of responsibilities

There may be a number of parties involved in a tunnelling project, such as:

- the PCBU
- the principal contractor
- designers
- people who employ workers at the site, including labour hire agencies providing workers to the site
- suppliers of plant, substances, materials or prefabricated components
- manufacturers of plant, and
- workers.

Where more than one party has responsibilities at a specific workplace, each party must discharge their responsibilities in a coordinated way.

2.1.2.7 Consultation and risk management

> The Act and the regulation require duty holders to address workplace health and safety through a process of consultation and risk management.

The way to systematically plan and manage health and safety in the workplace is to build risk management and consultation into all those activities that may have health and safety implications. This will include activities such as:

- purchasing
- work methods or procedures
- using contractors
- holding meetings before the start of each shift
- reporting health and safety problems
- investigating incidents, and
- planning emergency procedures.

Duty holders should, within their risk management system, prepare plans by consulting with fire and ambulance services regarding fire, rescue and hazardous materials issues, such as fire detection, gases and storage of hazardous materials. The plan should be practised regularly during the construction phase.

2.1.2.8 Consultation arrangements

> The PCBUs and principal contractors must set up consultation arrangements, and develop and implement consultation procedures for the workplace.

The Act provides for the following consultation arrangements:

- workplace health and safety committee
- workplace health and safety representative.

When the consultation arrangements have been decided, the PCBUs and principal contractors are required to record the arrangements and advise all existing and new workers of the arrangements.

2.1.2.9 When should consultation be undertaken?

After setting up the consultation arrangements, the PCBUs and principal contractors need to decide when and how these arrangements need to be applied. The PCBUs and principal contractor must consult with their workers when decisions are being made that may affect their health and safety.

Decisions which could affect health and safety include:

- eliminating or controlling risks
- identifying hazards
- assessing, reviewing and monitoring risks
- planning for new premises or modifying existing premises
- purchasing new plant, equipment or substances
- planning, designing or changing work tasks or jobs
- using subcontractors in the workplace
- investigating incidents or accidents
- developing emergency procedures, and
- determining or reviewing workplace amenities and consultation arrangements.

2.1.2.10 How should consultation be undertaken?

The Act requires PCBUs to:

- share all relevant information with workers, including any changes to work tasks
- advise workers about any risk to health and safety that may arise, and what will be done to eliminate or control these risks
- give workers adequate time to assess the information given to them, obtain relevant safety information and consult with fellow workers to enable them to form and express their views, and
- consider workers' views when deciding how to resolve any issues.

In many cases, agreement will be reached on how the health and safety issues can be addressed. When agreement cannot be reached, the PCBU and principal contractor should explain how the workers' concerns should be dealt with.

2.1.2.11 Managing risks in the workplace

Further guidance on risk management is available in the *How to Manage Work Health and Safety Risks Code of Practice.*

2.1.1.12 Hierarchy of control measures

> The Act requires that risks are eliminated, or prevented, and where this is not possible, the risks must be controlled by taking the following measures (in the order specified) to minimise the risk.

The following process must be followed:

- eliminate the hazard (e.g. choose a different construction method)

- minimise the risk by substituting the hazard with one of lesser risk (e.g. substitute the system of work or plant with something safer, or modify the system of work or plant to make it safer)
- isolate the hazard (e.g. introduce a restricted work area)
- introduce engineering controls (e.g. ground and dust controls)
- apply administrative controls, such as hazard warning signs (e.g. ‘tunnelling in progress’) and specific training and work instructions (e.g. manual tasks training), and
- use personal protective equipment (e.g. eye, respiratory and hearing protection).

The control measures that eliminate the hazard give the best results and should be adopted. The control measures that minimise the risk and other less effective measures (e.g. administrative controls) require more frequent reviews of the hazards and systems of work.

The control measures recommended by a subcontractor should be considered by the PCBU and principal contractor as part of the WHS Management Plan. Any new control measures should be evaluated to ensure that they are safe and effective, and that any new hazards created (directly or indirectly) by them are also controlled.

A combination of measures may be required to minimise the risk.

Further guidance on risk management is available in the *How to Manage Work Health and Safety Risks Code of Practice.*

2.2 Design for safe tunnel construction

Tunnel design differs significantly from plant design and other structures because of the difficulty of determining accurate geological properties and the potential variability of these properties along the tunnel.

Therefore, tunnel design is based on less reliable material property assumptions than most other designs. To reduce the risk resulting from this:

- Review existing geological information and undertake a site investigation to confirm the existing information and obtain more specific local geological information (see 2.2.1).
- Specify the geological conditions assumed in the design, including the relevant issues listed in section 2.2.1.
- Implement an inspection plan, as detailed in section 2.2.6, to compare the actual geological conditions as the excavation progresses with the assumed conditions.
- Implement procedures to assess the implications of any changes in conditions and reassess the adequacy of the tunnel design and ground support before the changes become a risk to health and safety. This may include ceasing relevant work while the reassessment is being conducted.

2.2.1 Site investigation

Safe tunnel construction depends on adequate pre-construction investigation of the ground and site, and proper interpretation of the information obtained.

Designers should be:

provided with all available relevant information
advised of gaps in the information for planning and construction

involved in the data acquisition for the site investigation program, and include on-site involvement during the site investigation.

Site investigations should be based on the nature, scope, extent and location of the project, and the environments. The investigation should provide sufficient information on site conditions, ground and groundwater conditions and previous history and constraints, in order to enable realistic assessments of different tunnelling methodologies and designs to be made.

The site investigation should be carried out by suitably qualified and experienced people, who are competent in conducting investigations of similar ground conditions. The site investigation may include undertaking the following studies:

- topography, geology and hydrology
- location, condition and influence of existing structures, services and old workings
- climate and prevailing weather conditions
- drilling of boreholes or examining existing borehole results
- assessment of properties of soils and rock, including collection of samples and laboratory testing
- geophysical investigation
- underground and structural survey
- groundwater tests – location, volume and effects on, or resulting from, tunnelling and changes in groundwater patterns
- rock cutting and dust production, and
- blasting trials.

The site investigation will provide information that can assist in the geotechnical risk assessment of ground and other conditions that should consider the following:

- rock mass geology
- planes of weakness
- mechanical properties of rock, planes and rock mass
- in-situ rock stress field magnitude and orientation
- induced rock stress field due to excavation
- potential rock failure mechanisms
- blast damage effects to the rock mass, if blasting is being considered
- likely scale and nature of the ground (e.g. movement)
- possible effects on other working places or installations
- groundwater presence and quantity
- possible contaminated environments – whether by gases, liquids or solids, including contamination of the groundwater (e.g. chemical plumes), and
- previous relevant experience and historical data for the area.

2.2.2 Tunnel design

The information obtained from the site investigation and the anticipated excavation methods should be considered in preparing a tunnel design.

The design should include:

- details on the tunnel dimensions and allowable excavation tolerances
- the final support and lining requirements for each location within the tunnel
- any other requirements for the finished tunnel.

It should also include information on the excavation methods and ground conditions considered in the design, to allow the design to be reviewed if another excavation method is chosen or the actual ground conditions change as the excavation proceeds (see section 2.2.6).

2.2.3 Design review for construction

The initial tunnel design, referred to in 2.2.2, should be reviewed before construction commences, usually by, or in consultation with, the PCBU and principal contractor, and should be amended if necessary in line with the construction needs, before excavation commences.
This review should consider a range of construction issues, such as:

- the excavation method
- additional excavation for temporary access
- ventilation
- spoil removal
- refuges
- rail sidings, and
- loadings from roof mounted spoil conveyors and ventilation systems.

As well as amending the tunnel design itself, the design review should produce concept designs which may include:

- ground support
- the ventilation system
- the construction electrical system
- the materials handling system.

Safe tunnel design and construction go hand-in-hand, and their suitability to the ground and environmental conditions, is more safety-critical in underground work than in any other construction activity. Consequently, continuity in engineering practices at the planning, investigation, design and construction stages is considered necessary.

This can be achieved more effectively by the involvement of a single organisation throughout. However, if the designer's direction changes, a way should be devised to ensure that the essential continuity is maintained and that the total planning, investigation, design and construction process is not fragmented.

2.2.4 Ground support design

Most tunnels and open excavations require some form of permanent ground support, which should be specified in the tunnel design referred to in section 2.2.2.

Removal of material causes unbalanced soil or rock stresses that reduce the capacity of the excavation to support itself. Varying geological conditions mean that control measures that have worked previously may not be satisfactory under these changed conditions.

The PCBU undertakes a detailed analysis of existing geophysical factors in conjunction with the design requirements (e.g. tunnel dimensions need to be undertaken), to identify the most appropriate temporary ground support that may be installed without requiring workers to work under unsupported ground.

An alternative to temporary ground support may be to use overhead protection. Ground support systems include engineering issues that involve both structural design and soil/rock mechanics. Using ground support, designed for the unique circumstances of the current situation, is essential to control the risk of a collapse or tunnel support failure.

Design specifications for engineering controls, such as shoring support structures, should be prepared by a competent person in accordance with relevant legislative requirements, Australian Standards, and codes of practice.

2.2.5 Ventilation system design

The ventilation system should be designed to provide adequate ventilation levels throughout the tunnel during construction, including providing additional localised extraction ventilation to deal with the production of dust, heat or fumes from the excavation process, operation of large plant or other activities, such as maintenance.

The design should allow for the need to install ventilation equipment or ducting as the excavation progresses to maintain adequate air supply to the working face.

2.2.6 Inspection plans

Excavation work, whether a tunnel or an open excavation, must be inspected at regular intervals to ensure that the excavation and supporting systems are stable and intact for the work to proceed safely.

The risk assessment must be used to determine an inspection plan, including the frequency, scope of the inspections, and appropriate competencies of the person(s) undertaking the inspections. The inspection frequency, whether based on time or on face advance[1], should consider the delay due to the assessment and reporting procedures established in section 2.2.7, so that any identified issues are dealt with before becoming a risk to health and safety.

The inspection plan should be reviewed based on the results of the inspections, after collapses or falls of materials, or after adverse weather conditions.

The following activities should be included in the inspection plan:

- mapping and visually assessing the actual ground conditions and excavated shape as exposed by the tunnel excavation
- monitoring support performance, including:
  - possible support failures, if any
  - any evidence of excessive load on supports
- falling or fretting ground
- monitoring time-based deterioration, such as spalling or slaking (e.g. weathering from temperature changes, humidity changes or exposure to air)
- monitoring groundwater inflows
- measuring closure or subsidence of roof or walls (e.g. by installing extensometers or by regular survey)
- anchoring or pulling out tests on supports
- testing core rocks

[1] This means how far the tunnel face has moved.

- measuring in-situ ground stresses, and
- reviewing the most recent air monitoring results.

Additional considerations for open excavations include:
- excavated and other material being placed within the zone of influence of the excavation
- machinery operating within the zone of influence of excavations causing weight and vibration influences
- surface soil falling into the excavation
- water seeping into excavations from side walls or base
- changes to soil and/or weather conditions
- surface water or run-off entering the excavations or accumulating on the surface near the excavation, and
- subsidence alongside the excavations.

2.2.7 Site-specific planning and preparation

2.2.7.1 WHS Management Plan

The regulation states that the principal contractor must ensure that a site-specific WHS Management Plan is prepared for the project before the work commences. The principal contractor must also ensure that the plan is maintained and kept up-to-date during the course of the work. The plan must include:
- the duties of specified people or positions
- the arrangements for ensuring health and safety induction training
- the arrangements for reporting and recording incidents
- site-safety rules and the manner of communication to all people at the site, and
- safe work method statements for high risk construction activities.

Assessment and reporting procedures should be developed in accordance with the inspection plan before excavation commences, and reviewed as part of the inspection plan review. These procedures should include reporting means for both routine and urgent reporting, where changes, identified as excavation conditions, are assessed as requiring modification to the ground support requirements or otherwise, represent a risk to health and safety.

Where the assessment is being carried out by the same person(s) undertaking the inspections, it may be appropriate for the urgent reporting to include providing advice to the person responsible for the tunnel construction.

The effective communication of this information is critical at the worksite. Valuable information can be exchanged between people on outgoing and incoming shifts about:

the status of the work being performed
- the state of the work place
- any changes to work methods required, and
- any relevant safety information or other issues that exist at the workplace.

All workplaces should be thoroughly inspected by the incoming shift to ensure that the place is safe for work to commence. The Act places a duty on the PCBU and principal contractor to provide all necessary supervision to ensure safety. So people with health and safety responsibilities outlined in the WHS Management Plan should have the necessary authority to perform and implement their supervisory duties.

2.2.7.2 Safe work method statements

The regulation states that the PCBU must prepare safe work method statements where high risk construction activities are to be performed. Many activities associated with work in tunnels are high risk construction activities, and require safe work method statements.

The safe work method statement:

- describes how the work is to be carried out
- identifies the work activities assessed as having health and safety risks
- identifies the health and safety risks, and
- describes the control measures that will be applied to the work activities.

A safe work method statement requires the work methods to be presented in a logical sequence. The hazards associated with each process are to be identified, and the control measures specified. Break down each job into a series of basic steps to identify the hazards and potential accidents in each part of the job. The description of the process should not be so broad that it leaves out activities with the potential to cause accidents, and prevents proper hazard identification.

The safe work method statement could also be used to nominate:

- the competencies
- the number of workers and items of plant required to safely perform the task(s)
- any permits and licences required under the regulation.

It may be useful to provide copies of these documents and training records with the safe work method statement.

Workers should be involved and consulted during the development and implementation of any safe work method statement. All people involved in carrying out the work should understand the safe work method statement before commencing work.

2.2.7.3 Communication systems

Good communication is fundamental to the health and safety and efficiency of all aspects of the tunnel project, particularly in:

- passing on information and instructions
- monitoring systems
- the control of operations, such as lifting, transporting people, materials and plant
- coordinating maintenance, and
- managing emergencies.

The communication system should be used to link major workplaces, tunnel portal and face(s), or shaft top and bottom, site offices and safety critical locations on-site (e.g. first aid room or emergency control room). Ways of contacting the emergency services from the site should be available, manned and monitored at all times.

The communication system may also be used to pass on information on a variety of safety-related items, such as machine-condition monitoring, instrumentation monitoring, atmospheric monitoring and fire alarms.

The risk assessment should determine whether communication with all mobile vehicles, including personnel transporters, is required. Where electronic communication (non voice) methods are being relied on, the point of communication reception (e.g. control room), should be monitored at all times by people who have been trained in the emergency action plan.

The PCBUs must be able to communicate requirements for materials and equipment, and raise the alarm and receive instructions in the event of an emergency. The system adopted should depend on the:

- size and length of the tunnel
- number of people in the tunnel
- system of tunnelling used, and
- potential hazards, including the speed of operations.

A system of signalling by bells or by coloured lights can be appropriate for routine communications, such as controlling train movements or requesting that lining segments or other materials be sent forward.

Details of any signal code adopted, whether audible or visual, should be communicated effectively to all affected by the operations under way (e.g. at the top and bottom of each shaft or incline, and in clear view of the operator).

The communication system should be independent of the tunnel power supply and installed so that destruction of one unit or the occurrence of a collapse will not interrupt the use of the other units in the system. All wiring, especially that used to transmit warnings in an emergency, should be protected. All communication cables needed to transmit warnings in an emergency should have increased integrity under emergency conditions, such as fire, water or mechanical shock.

At all working shafts, a standby means of communication should be available and able to be operated from any position throughout the depth of the shaft.

The codes for both audible and visual signals, as well as call signs and channel allocation, should be displayed at strategic locations for all operators. In the case of shafts, this applies to the doggers, winch and hoist drivers, and all those working in or about the shaft itself.

The WHS Regulation requires that a PCBU must manage risks to the health and safety of a worker associated with remote or isolated work. In minimising risks to the health and safety of workers associated with remote or isolated work, a PCBU must provide a system of work that includes effective communication with the worker.

There needs to be an effective method of warning all persons underground that the tunnel is to be evacuated and which can be activated quickly in the event of an emergency call. Emergency warning systems need to be tested, using emergency evacuation drills.

2.2.7.4 Amenities

The regulation requires that principal contractors ensure that appropriate amenities are available for workers. To determine the appropriateness of amenities, principal contractors must take into account:

- the nature of the work undertaken
- the placement of amenities and their access – entry away from traffic
- the size and location of the workplace, and
- the number of people at the workplace.

Underground crib[2] facilities should be located away from dusty environments, or if possible, have filtered air under positive pressure (for example a RESPA type system).

The amenities cleaning regime should consider shiftwork or around the clock work shifts (e.g. amenities should be cleaned more often than would be done for one shift).

The supply and location of potable water should be reasonably available to workers.

2.2.7.5 Personal protective equipment (PPE)

The use of PPE to control risks is the lowest form of control in the hierarchy of control, and should only be used when other control measures are impracticable or when a residual risk remains after implementing other controls.

PPE selection and suitability
Where PPE is to be used, it should be appropriate for the risk and comply with the relevant Australian Standards. Workers should be competent in the proper selection, use and maintenance of the PPE, and be provided with proper supervision and monitoring conducted to ensure it is used properly. PPE should be regularly inspected, maintained and replaced as necessary.

Clothing for protection against chemicals
Where there is a risk that workers may be exposed to chemicals or contaminated environments, they should wear protective clothing. Guidance for protection against hazardous chemicals can be found in AS/NZS ISO 6529, AS/NZS 4503.2 and AS/NZS 4503.3.

Eye protection
Dust, flying objects and sunlight are the most common sources of eye damage in excavation work. Where people are cutting, grinding or chipping concrete or metal, or welding, they should be provided with eye protection. Guidance can be found in *AS/NZS 1337 – Eye and face protectors series.* Eye protection complying with AS/NZS 1337 could also be provided where people carry out other work, such as carpentry or chemical handling, where there is a risk of eye injury. Guidance on selection, use and management of eye protection can be found in *AS/NZS 1336 – Recommended practices for occupational eye protection*.

[2] Crib room is a mining term for lunch room.

For tunnelling activities, such as rock drilling, rock cutting, concreting, service installing, steelwork and plant maintenance, the risk assessment would probably identify an increased risk of eye injury requiring eye protection to be worn at all times.

Some above ground work will also require eye protection from sunlight UV radiation.

Fall-arrest equipment

Guidance in the selection, use and maintenance of fall-arrest equipment may be found in *AS/NZS 1891.4 – Industrial fall-arrest systems and devices – Part 4: Selection use and maintenance.*

Hearing protection

Where there are no other hierarchical control measures for people exposed to excessive noise, personal hearing protection that complies with *AS 1270 – Acoustics – Hearing protectors* should be provided. Guidance on control measures, including training may be found in *AS/NZS 1269.3 – Occupational noise management – Hearing protector program*.

High visibility garments/safety reflective vests

People working underground or near traffic, mobile plant, or equipment under operator control, should be provided with and use high visibility garments. Such garments should be selected, used and maintained in accordance with *AS/NZS 4602.1 – High visibility safety garments – Garments for high risk applications*. Other clothing not covered by the high visibility garment should be light coloured, and all garments should be selected for best contrast with the surrounding background.

Respiratory protective equipment

Where people could be exposed to harmful atmospheric contaminants, such as siliceous dust, diesel particulate matter and welding fumes, respiratory protective equipment that complies with *AS/NZS 1716 – Respiratory protective devices* (providing it is within the performance capability of the PPE) should be provided. Such equipment should be selected and used in accordance with *AS/NZS 1715 – Selection, use and maintenance of respiratory protective equipment*. Persons using respiratory protective equipment must be provided with information, instruction and training in use of the equipment (for example, for the equipment to be effective a person needs to be clean shaven).

Safety helmets

The use of safety helmets may prevent or lessen a head injury from falling objects or a person hitting their head against something. Where there is a likelihood of people being injured by falling objects and overhead protection is not provided, people must be provided with, and use, an appropriate safety helmet. Appropriate safety helmets should also be provided and used where a person may strike their head against a fixed or protruding object, or where there is a risk of accidental head contact with electrical hazards.

All people on a tunnel project should wear head protection that complies with *AS/NZS 1801 – Occupational protective helmets* and be selected and used in accordance with *AS/NZS 1800 – Occupational protective helmets – Selection, care and use*.

Safety gloves

Where there is a risk of hand injury, such as exposure to a harmful substance, excessive heat or cold, or to a mechanical device, hand protection that complies with *AS/NZS 2161 – Occupational protective glove set* should be provided and used.

Self-rescuers
Where people could be exposed to harmful atmospheric contaminants beyond the capacity of the ventilation system or respiratory protective equipment, self-rescuers should be provided to each worker, and be available for use by the worker, in an emergency to give the user sufficient oxygen to walk to the surface, or a designated sealable respirable air equipped refuge. The size of the self-rescuer (e.g. minutes) needs to relate to the maximum distance the worker may have to walk (via either their primary or secondary means of exit) to a safe place of refuge or the surface.

Waterproof clothing
Waterproof clothing provided for work conditions, weather or site conditions should be effective and suitable for the task. Waterproof clothing should also incorporate light reflective features in accordance with the high visibility requirements in *AS/NZS 4602.1 – High visibility safety garments – Garments for high risk applications.*

2.2.7.6 Hazard and incident reporting

Hazards and health and safety issues should be reported as soon as they are noticed so that the risks can be assessed and addressed as quickly as possible. Records of reported hazards should be kept and include details of the action taken to remove the hazard or control the risk arising from the hazard.

The Act and the regulation also prescribe a number of requirements concerning incident and injury reporting.

2.2.7.7 First aid

To ensure adequate first aid provisions, the PCBU should:
- identify their potential injuries and illnesses
- assess their first aid requirements, and
- consult with workers in the process.

When determining the nature, number and location of first aid facilities and equipment, and the number of trained first aid personnel needed, the PCBU must take into account the location and type of work being undertaken.

The type of work performed will influence the hazards and the possible harmful consequences for workers. For example, office workers may have different first aid requirements from construction workers.

Workplaces using hazardous chemicals may require specialised first aid facilities, such as eyewash stations and emergency showers. The risk assessment process will assist in identifying the particular needs of the workplace.

Where a first aid room is supplied, it should only be used for first aid or health and safety purposes.

2.2.7.8 Preparation, maintenance and implementation of emergency plan

A person conducting a business or undertaking at a workplace must ensure that an emergency plan is prepared for the workplace that provides for the following:

(a) emergency procedures, including:
  - (i) an effective response to an emergency; and
  - (ii) evacuation procedures; and
  - (iii) notifying emergency service organisations at the earliest opportunity; and
  - (iv) medical treatment and assistance; and
  - (v) effective communication between the person authorised by the person conducting the business or undertaking to coordinate the emergency response and all persons at the workplace;

(b) testing of the emergency procedures, including the frequency of testing;

(c) information, training and instruction to relevant workers in relation to implementing the emergency procedures;

(d) first aid and rescue procedures to be followed in the event of an emergency in the tunnel or other confined space.

The first aid, escape and rescue procedures applicable for an emergency in the tunnel or a confined space must be initiated as soon as practicable in an emergency.

A person conducting a business or undertaking at a workplace must maintain the emergency plan for the workplace so that it remains effective.

The person conducting the business or undertaking must consider all relevant matters including:

(a) the nature of the work being carried out at the workplace; and
(b) the nature of the hazards at the workplace; and
(c) the size and location of the workplace; and
(d) the number and composition of the workers and other persons at the workplace.

A person conducting a business or undertaking at a workplace must implement the emergency plan for the workplace in the event of an emergency.

The preparation of an emergency plan for a workplace shared by a number of PCBU's (e.g. contractors, subcontractors, suppliers, emergency service organisation) must be prepared in consultation and cooperation with all PCBU's who share the workplace. The person with management or control of the workplace (e.g. the principal contractor) should co-ordinate the consultation.

If the workplace presents a significant hazard in an emergency or the emergency plan includes a potential role for an emergency service organisation such as Queensland Fire and Rescue Services then the PCBU must consult, cooperate and coordinate with the emergency service organisation in the preparation, maintenance and implementation of the emergency plan. The PCBU should provide a copy of the emergency plan for the workplace to the emergency service organisation prior to work commencing or after any review to ensure the duty to consult, cooperate and coordinate has been fulfilled.

If the emergency service organisation gives the person a written recommendation about the content or effectiveness of the emergency plan, the person must revise the plan in accordance with the recommendation or in another agreed way.

If the emergency plan does not include any role for an emergency service organisation then the risk assessment completed for work conducted in the tunnel should document why there is no role for an emergency service organisation.

Workers and their health and safety representatives must be consulted when reviewing, and if necessary revising, the emergency plan by the person responsible for preparing it.

All rescue-related safety measures have to be brought together and described in detail in the emergency plan. Fundamentally, the rescue measures regarding tunnel construction projects are divided into self-rescue measures and rescue measures taken from outside the tunnel. The importance of self-rescue rises with the length and the difficulty of the access which the emergency services have to pass before reaching the place of the incident. Time and energy for performing necessary self-rescue measures are determined by the expected maximum time period between the occurrence of the event and the arrival of the emergency services at the place of the incident. The maximum allowed number of persons within the tunnel has to be taken into account when determining safety facilities and rescue capacity.

The emergency procedures in the emergency plan must clearly explain how to respond in various types of emergency, including how to evacuate people from the workplace in a controlled manner. The procedures must be written clearly and simple to understand.

The triggers for evacuation of the tunnel need to be carefully set out, and should include:

- confirmed or suspected underground fire irrespective of size;
- compromised primary ventilation system (fans and/or intakes, ventilation controls) which impacts on the integrity or readiness of the emergency plan;
- failure of fire fighting systems (e.g. loss of water supply if the tunnels partly rely on sprinkler systems);
- compromised primary ventilation intake air (an example could be a surface fire or chemical spill which could affect the fresh air intakes). For this reason, great care should be taken in allowing combustible or toxic material (diesel fuel storage, heavy vegetation, ammonia refrigeration plants, etc) near fresh air intakes;
- seriously compromised emergency system equipment (communication equipment, breathable air systems, emergency lighting, recall of self-rescuers, etc).

Types of emergencies considered should include:

- treatment and evacuation of a seriously injured person
- fire underground (e.g. fire on a tunnel-boring machine (TBM) or a truck)
- sudden flooding (e.g. inrush from an underground water feature)
- underground explosion (e.g. methane ignition or other airborne gases, vapours and dusts)
- hazardous atmosphere (e.g. harmful concentrations of any airborne contaminants or an atmosphere that does not have a safe oxygen level)
- tunnel collapse, resulting in people being trapped
- power failure, and
- above ground emergency that compromises tunnel safety (e.g. fire or chemical spill).

The PCBU should ensure that, in the event of an emergency at a project, arrangements have been made for:

- allocation of roles and responsibilities for specific actions in an emergency to persons with appropriate skills — for example, appointment of area wardens
- clear lines of communication between the person authorised to co-ordinate the emergency response and all persons at the workplace
- the activation of alarms and alerting staff and other people at the workplace
- the safety of all the people who may be at the workplace in an emergency, including visitors
- workers or other persons who will require special assistance to evacuate
- specific procedures for critical functions such as a power shut-off
- identification of safe places
- potential traffic restrictions
- distribution and display of a site plan that illustrates the location of fire protection equipment, emergency exits and assembly points
- the distribution of emergency phone numbers, including out-of-hours contact numbers
- access for emergency services (such as ambulances) and their ability to get close to work area
- the safe and rapid evacuation of people from the workplace
- appropriate medical treatment of injured people
- regular evacuation practice drills (at least every six months or as soon as practicable after the plan has been amended)
- the use and maintenance of equipment required to deal with specific types of emergencies (for example, spill kits, fire extinguishers, early warning systems such as fixed gas monitors or smoke detectors and automatic response systems such as sprinklers), and
- regular review of procedures and training.

The following emergency response control measures should be implemented:

- providing a system to identify who is underground (e.g. a tag board)
- developing site emergency procedures appropriate for the level of risk, including establishing an emergency assembly area and a plan for contacting, and subsequently interacting with emergency services
- providing emergency response equipment and training in how to use it
- providing control measures to reduce the severity of the emergency (e.g. self-closing bulkheads to control water inrush)
- providing fire suppression on vehicles, and
- providing self-rescuers, breathing apparatus and sealable, self-contained atmosphere refuges as well as instruction and practice in how to use the equipment.

Risk assessments determine if special emergency provisions, such as emergency rescue cages and means to extract people from difficult locations (e.g. from the base of a shaft or heading of a tunnel), are needed.

Traffic management rules should be implemented to ensure vehicles and mobile plant park in a way that prevents potential runaway and enables clear access at all times.

Emergency procedures must be tested in accordance with the emergency plan in which they are contained.

Evacuation procedures should be displayed in a prominent place, for example, on a noticeboard. Workers must be instructed and trained in the procedures.

Further guidance on emergency plans and procedures is available in *AS 3745 – 2010 Planning for Emergencies in Facilities.*

2.2.7.9 Fire and explosion

The PCBU and principal contractor have a duty to control risks associated with fire and explosion.

Fire in an underground workplace is of particular concern, as the rapid consumption of oxygen and the production of noxious fumes and gases makes the severity of this risk extreme. In addition to the production of noxious fumes and gases a fire will reduce, and in some cases eliminate, visibility and there is a significant risk that the fire will block at least one means of exit from the tunnel forcing workers to seek an alternate exit or safe refuge.

While there are combustible materials present in a tunnel the risk of fire is always present, every tunnel construction project must be prepared for such an event. The principal contractor and all PCBU's must ensure that all working areas, installations and equipment used, in a tunnel construction project, are managed in such a way that the initiation or support of a fire or combustion is eliminated or minimised as far as is reasonably practicable.

An emergency preparedness plan should be in place and understood by all personnel working in the tunnel and adequate appliances for the suppression of fire should be provided.

Diesel powered equipment is associated with a significant risk of fires. Many of these fires result from hydraulic or fuel hose failures, allowing oil or fuel to spray on to hot parts, sparking from abraded direct-current (DC) power leads damaging fuel lines, hot surfaces such as exhausts and turbochargers and binding brakes causing grease fires in wheel hubs and igniting tyres.. Other potential ignition sources include naked flames, hot work (e.g. welding, cutting and grinding), electrical equipment and sources of static electricity, near flammable substances, dusts or waste materials.

Diesel Equipment Fire Precautions
All diesel equipment operating within the tunnel should be inspected for fire risk by a competent person. Consideration should be given to modifications and systems to minimise the incidence and severity of fires associated with diesel equipment, including:-

- fitting loaders, trucks, turbocharged vehicles and other vehicles larger than 125kW with a fixed Aqueous Film Forming Foam (AFFF) or Film-Forming Fluoroprotein (FFFP) system or another equivalent fire suppression solution;
- the installation of brake drag/brake temperature indicators;
- the suitable fusing and insulation of high current electrical systems;
- a fail safe engine shut down system;
- the installation of engine fire walls, in particular in loaders;
- the relocation of electrical wiring and hydraulic hosing from the engine compartment;
- the shielding of hot parts from possible oil or fuel spray;
- the provision of fire fighting equipment in accordance with Australian Standard AS 2444 "Portable Fire Extinguishers- Selection and Location"; and
- the integration of the activation of the AFFF system with the engine management system.

Hot Work Procedure
Where a blow torch, welding, cutting or other hot work equipment is used underground in a location where a fire may endanger a tunnel entrance or exit or where the fumes from the fire may jeopardise the safety of persons in the tunnel, implementation of standard written procedures for the safe use of such equipment is essential. In critical or identified fire risk areas a "work permit" system is warranted.

Electrical Equipment
Procedures and suitable fire fighting facilities should be in place and notices placed close to electrical installations to ensure correct procedures are followed in case of fire. Fire fighting equipment is best located on the ventilation intake side of the hazard.

Training For Underground Fire Emergency
Effective training is probably the most crucial factor determining the success of personnel protection strategies. Training should include:-

- basic recognition of fire hazards and fire prevention;
- response to various types of fires (eg. selection and use of extinguishers);
- use of communication systems and emergency message techniques;
- when and how to use self rescuers, and their limitations;
- orderly evacuation procedures and use of escape routes;
- use of refuge chambers and fresh air bases;
- survival techniques when trapped or lost underground; and
- occupational first aid.

In addition PCBUs should ensure the following control measures when implementing fire prevention procedures:

- eliminating activities that could generate flammable or explosive atmospheres, or control the generation by providing adequate ventilation
- removing unnecessary flammable substances, dusts or waste regularly
- providing an appropriate number and type of fire extinguishers strategically located around the site (including flammable goods storage areas)
- highlighting fire extinguishers, fire hoses and hydrants so they are easily identifiable and easily accessed
- providing flammable goods storage areas, identified with appropriate warning signs
- providing automated fire protection where possible – this may depend on the type and size of plant used, particular nature of the tunnel, difficulty of egress underground work areas and also the potential for fire
- developing site emergency procedures appropriate for the level of fire risk, including establishing an emergency assembly area, and
- providing self-rescuers, breathing apparatus and sealable, self-contained atmosphere refuges as well as instruction and practice in how to use the equipment.

2.2.7.10 Record keeping

Keeping other relevant health and safety records could increase the effectiveness of the risk management system. These records could include:

- subcontractor monthly safety reports
- risk assessments

- workplace environment reports (occupational hygiene, e.g. dust, diesel particulate matter (DPM), noise, carbon monoxide, heat and ventilation)
- geotechnical reports
- inspection reports (e.g. of plant)
- workplace inspection reports
- minutes of safety meetings/site meetings
- incident/accident investigation reports
- non-conformance reports, and
- site instructions and diary notes.

2.2.7.11 Existing services

Before excavation work is to be performed, the location of any underground services, such as gas, water, sewer, electricity and telecommunication cables, must be identified by the principal contractor. Prescribed information about the services is to be recorded in writing and given to the PCBU who is to do the excavation work.

The PCBU carrying out the work should make sure they are aware of the location of any other unknown or hidden underground services. They can do this by:
- contacting organisations that can assist in locating underground services
- using remote location devices
- using gas detectors, and
- being alert for signs of disturbed ground, warning tape or pavers during excavation.

Workers who may be affected by underground services should be advised of their location. Appropriate control measures, including the protection, support or removal of services, should be implemented, after consultation with the relevant service providers, to ensure the health and safety of workers.

For underground electrical services that have not been removed or de-energised, hand excavation in the vicinity should only be undertaken using tools with non-conductive handles and while wearing rubber boots and insulating gloves. Guidance on gloves for electrical purposes can be found in *AS 2225 – Insulating gloves for electrical purposes.* Gas lines that have been disconnected should be 'blown down' to remove residual gas before commencing work.

2.2.7.12 Entry, Exit and Escape Routes

When conducting a risk assessment about safe entry and exit to, from and within the workplace, the following must be considered:
- the layout and condition of the premises, including the presence of any confined spaces
- the physical working environment, including the potential for people slipping, tripping or falling
- how to avoid objects or structures falling on people, and
- how to control the risks to visitors coming onto the worksite.

An assessment should also take into account:
- the number of people using particular entry and exit points
- any tools and equipment that may need to be carried to or from the worksite
- lighting, ramps, walkways, stairways, scaffolding and ladders.

Examples of hazards include:
- wet or oily floors or surfaces
- untidy work areas
- cluttered passageways
- steep or slippery steps
- exposure to plant
- poorly-lit work areas
- trenches, steel reinforcing or bars prior to concrete pours and vertical benches at blast sites.

Control measures that could be introduced include:
- installing overhead and fall protection
- storing materials and plant
- keeping work areas and passageways clear and free of obstructions
- removing rubbish, including construction waste and excavated material
- providing handrails
- implementing traffic management controls, including collision avoidance guidelines on the surface and underground
- erecting safety fences and warning signs, and
- providing non-slip surfaces on passageways and work platforms on plant and machinery.

ESCAPE ROUTES

An alternative escape route for tunnel workers must be available. Examples of escape routes include connected parallel tunnels, return airways or exhaust shafts. In a fire emergency such airways can be expected to have limited visibility and may have an irrespirable atmosphere. . Some of these could be chimneys in the event of a fire. Exhaust shafts should never be the second egress.

Integrity of Escape Routes to Surface

Escape routes that cannot be maintained in fresh air with certainty during an emergency should be evaluated to determine if they should or should not be used in the event of fire.

The initial problem confronting an underground worker in the event of a fire is securing an immediate supply of breathable air. This is normally addressed by supplying everyone working underground with an oxygen-generating self-contained self-rescuer (SCSR). These devices come in various designs, and allow a person to travel from an endangered position to the surface or a safe haven.

It is recommended that the maximum distance separating a worker from the surface or a safe haven (e.g. a refuge chamber) be based on how far a person, in a reasonable state of physical fitness, can travel at a moderate walking pace, using 50% of the nominal duration of the SCSR. If it is assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety.

This distance should be regarded as an absolute maximum because:

- the duration of the SCSR can be adversely affected by the wearer's state of agitation
- physical difficulties may be encountered while travelling
- smoke from a fire underground may be so thick that crawling is the only feasible means of movement.

The alternative to using the escape routes to surface is to use refuge chambers, fresh air bases or a combination of these. Workers should be notified through induction and regular retraining on where to report in a fire emergency. Refuge chambers should be sited near active workplaces, taking into account the needs of people working there and potential hazards they face.

Vehicles within the tunnel introduce a significant risk to the health and safety of workers. Vehicles increase the risk of fire, risk of death or injury resulting from coming into contact with vehicular traffic or moving plant, and risk compromising the integrity of an escape route by blocking or hindering access.

The principal contractor should establish a permit system for vehicles entering the tunnel to ensure:
- Vehicles have been modified to minimise fire risk;
- The number of vehicles in the tunnel at any time is minimised;
- The number and location of vehicles in the tunnel is known;
- Workers have been provided with information, instruction and training for driving the vehicle within the tunnel and where to park the vehicle to ensure escape routes and access to services or emergency equipment are not blocked or compromised.

Escape Route Signs
Escape route signs and notices posted in the tunnel, should be properly maintained and marked in accordance with the Regulations and Australian Standard AS 1319. They should also be conspicuous and located at a low elevation in order to be visible in smoke. In areas that are difficult to traverse in low visibility, the strategic placement of lighting, ropes or chains to guide employees to safe egress is of benefit.

Unfamiliar Escape Routes
Escape routes from the workplace may include travelling in parts of the tunnel not normally travelled by some employees. All floor openings should be fenced and the escape route well marked.

Rescue Team Access
All escape routes and ladderways giving access in a tunnel should be of sufficient dimensions to permit stretchers and rescue team members using breathing apparatus to pass without undue hindrance.

Entrapped Procedure
All persons who are required to work or visit a tunnel need to be instructed in entrapped procedures, or be accompanied by a person with the knowledge of entrapped procedures. An incidence of fire or explosions in the tunnel can expose a person or persons to an irrespirable atmosphere, where escape to the surface, a fresh air base or refuge chamber is not possible.

There are several courses of action to be included in the training, depending on the resources available. These can be summarised as follows:-

- compressed air available;
- compressed air not available;
- using an oxygen self rescuer; and
- using more than one self rescuer.

Decisions to be made by the entrapped person need to be conservative in order to avoid unwarranted risk, and having decided upon an action, the person needs to remain calm and relaxed, but alert. It may be necessary to respond to changes in the circumstances whilst awaiting rescue.

Underground Refuge Chambers

The primary function of a tunnel refuge chamber is to provide a safe haven for people working in the immediate area in the event of the atmosphere becoming irrespirable.

The location of refuge chambers in the tunnel should be based on strategic rather than convenience factors. Tunnelling activity, ventilation and proximity to working places should be evaluated in the tunnel planning process when determining the siting of refuge chambers. The duty holder should be aware of the time limitations and active duration of the self rescuers used at the tunnel, and this information should be taken into consideration when locating refuge chambers. In many instances a refuge chamber will replace an alternative exits that could become contaminated in a fire situation.

The chamber size should recognise that other personnel such as supervisors, surveyors, geologists and service technicians may also need to use the facility. The number of such people in the workings from time to time can require:

- provision for a refuge capacity more than double that determined from the size of the locally operating crew alone; or
- implementation of a system to limit the number of personnel in the area.

Sufficient refuge chambers should provide for all persons at risk and should be capable of supporting life for 36 hours of entrapment without external power or services. The communication system with the refuge chambers must be designed so that communication cannot be disrupted during an emergency.

The induction process and emergency procedure should specify if workers are to proceed to refuge chambers or escape routes from the tunnel in the event of fire. All emergency related information signs should be in accordance with Australian Standard AS 1319.

2.2.7.13 Site security

The site is to be secured by perimeter fencing that complies with the regulation. Signs showing the name and contact telephone number, including after hours emergency number of the Principal Contractor, are to be erected around the site, and clearly visible from outside the site.

Additional consideration should be given to the security of authorised visitors visiting the site (e.g. delivery drivers or people attending meetings).

The following control measures should be considered:

- locating offices, parking and delivery areas away from hazardous areas
- isolating the hazardous area with perimeter fencing, barricades, screens, barriers, handrails and/or covers, which are capable of preventing access or a person from falling
- providing visitor tags, tag in and out or logged security card access for specific areas
- removing or lowering ladders when not in use
- immobilising plant to prevent unauthorised use
- installing hazard warning lights, signs, markers or flags
- using security guards
- locking fuel dispensers, and
- installing night lighting.

2.2.7.14 Identification and Location of Persons in the Tunnel

A method is required to determine quickly and accurately the names and working locations of all persons in the tunnel. This is commonly achieved by use of a tag board that is checked by all supervisors at the start and end of every shift, and by the use of daily time sheets.

The integrity of such systems should be maintained at all times. The presence of an additional tag, or the absence of one is critical in determining search and rescue criteria for tunnel rescue team briefing, and can cause unnecessary delays where time is precious. During an emergency people may be exiting the tunnel via alternate routes, the system must be sufficiently robust to ensure that these persons exiting the tunnel are accounted for and the rescue team are not searching for a person who has already exited the tunnel.

Identification and Possible Location of Unaccounted Persons
A system is required that is able to determine quickly if and how many persons are trapped in the tunnel and their approximate locations, preferably prior to the tunnel rescue team reporting for instructions. Persons located in refuge chambers or fresh air bases should be instructed to remain there and to contact base only if their safety conditions change or other persons arrive.

All Persons Evacuating the Tunnel to Report
An established routine is required where persons evacuating the tunnel are checked against the list of persons known to be in the tunnel. This may require a person to be posted at each of the surface openings (muster points) of emergency escape routes to ensure they are unlocked and unobstructed, and to arrange orderly transfer to the emergency headquarters for debriefing. Any person leaving the tunnel during an emergency should be required to personally sign out. This will ensure that everyone can be accounted for within the duration of the emergency.

Information, Instruction and Training
Prior to any person being issued a tag or other permit to enter the tunnel they must be provided with information, instruction and training to the extent necessary to protect them from risks to their health and safety arising from work carried out in the tunnel.

The duty holder 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; and
- the nature of the risks associated with the work at the time the information, training or instruction is provided; and

- the control measures implemented.

3. Information, instruction, training and supervision

The Act requires the PCBU to provide information, instruction, training and supervision that may be necessary to ensure the health, safety and welfare of their workers and other people while at work**.**

Also**,** some activities are restricted to people holding the relevant certificate of competency (e.g. to erect scaffolds over four metres and operate cranes and some load shifting equipment).

3.1 Providing information and instruction

Information may include:
- the results of any applicable risk assessments
- safe work method statements
- a review of risk assessments and/or safe work method statements or operating procedures, and
- any other relevant health and safety information.

The PCBU should discuss with each of their workers the contents of risk assessments and safe work method statements, before each worker starts tunnelling work, then at regular intervals or, whenever there are changes to risk assessments, or new information about health and safety risks becomes available.

Workers should have, on request, ready access to risk assessments and safe work method statements.

3.2 Induction training

All PCBUs and workers doing construction work in Queensland **must** have successfully completed a general safety induction course, recognised by Queensland law before they start construction work.

3.3 Training topics

Training should draw on knowledge of the known hazards and risks in specific tunnel operations, including issues described in this code of practice. The source of risks should be pointed out and the adverse outcomes that have been experienced by others should be used to stress the importance of safety.

The training provided and the instructions given should include:
- all work methods to be used on the job, including issues described in this code of practice (e.g. all hazards, risks and control measures for control of underground hazards, including gases, atmospheric contaminants and ventilation, ground support and tunnel plant)
- all information and procedures relevant to controlling risks (this may include regularly updated geotechnical risks and control measures)

- dust, gas and fire risks that may be present and the control measures adopted, including procedures to follow, if equipment such as dust extraction fails
- the correct use, care and storage, in accordance with the manufacturer's recommendations or Australian Standards (where appropriate), of plant and associated equipment, personal protective equipment and tools
- traffic management rules and procedures on the surface and underground
- how to observe any administrative controls, such as restrictions on entry and warning signs, and
- emergency and evacuation procedures, including recognising the fire alarm, fire fighting measures, the location of fire fighting equipment and other emergency equipment, the use of fall-arrest equipment, confined spaces entry procedures, and the rescue of entrapped people.

The content of health and safety training should be tailored to suit the particular work activities and conditions of the workplace and should be based on the risk assessments being carried out.

3.4 Who should receive training?

The target groups for training at a workplace include:

- managers and supervisors of workers and/or other people undertaking the tunnelling work and/or have responsibility for implementing safe operating procedures
- members of health and safety committees and health and safety representative(s)
- staff responsible for the purchasing and maintenance of plant, PPE and for designing, scheduling and organising work activities
- people operating specialised equipment that do not have regulated licensing requirements under the Act (e.g. rock bolt machines, shotcrete rigs, airlegs and rambors)
- people undertaking risk assessments or preparing safe work method statements, and
- workers undertaking the tunnelling work, including workers of labour hire organisations.

The needs of each target group are different and the content and methods of presenting training material should be tailored to meet the specific needs of each group.

3.5 Supervision

The PCBUs must ensure that workers are provided with supervision necessary to ensure the health and safety of the workers and any other persons at the PCBU's workplace.

Supervision must be undertaken by a competent person and should take into account the competence, experience and physical ability of each worker.

4. Managing risks during tunnelling

A person conducting a business or undertaking must ensure, so far as is reasonably practicable, the health and safety of:

(a) workers engaged, or caused to be engaged by the person; and

(b) workers whose activities in carrying out work are influenced or directed by the person

while the workers are at work in the business or undertaking.

A person conducting a business or undertaking must ensure, so far as is reasonably practicable, 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.

Control measures to prevent people being injured during all stages of the tunnel construction and fit-out must be provided and maintained as part of a safe system of work.

A person conducting a business or undertaking must manage risks to health and safety associated with tunnel construction including risks associated with entering, exiting, working in, on or in the vicinity of the tunnel. The PCBU should ensure that a risk assessment, recorded in writing, is conducted by a competent person prior to the work commencing.

The risk assessment must be reviewed and as necessary revised by a competent person to reflect any review and revision of control measures implemented so as to maintain, so far as is reasonably practicable, a work environment that is without risks to health or safety.

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.

A duty holder, in managing risks to health and safety, must:

- eliminate risks to health and safety so far as is reasonably practicable; and
- if it is not reasonably practicable to eliminate risks to health and safety—minimise those risks so far as is reasonably practicable.

If it is not reasonably practicable for a duty holder to eliminate risks to health and safety then they must minimise risks, so far as is reasonably practicable, by doing one or more of the following:

- substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk
- isolating the hazard from any person exposed to it
- implementing engineering controls.

If a risk then remains, the duty holder must minimise the remaining risk, so far as is reasonably practicable, by implementing administrative controls and then by ensuring the provision and use of suitable personal protective equipment.

A combination of controls may be used to minimise a risk, so far as is practicable, if a single control is not sufficient for the purpose.

A duty holder who implements a control measure to eliminate or minimise risks to health and safety must ensure that the control measure is, and is maintained so that it remains, effective, including by ensuring that the control measure is and remains:

- fit for purpose; and
- suitable for the nature and duration of the work; and
- installed, set up and used correctly.

A duty holder must review and, as necessary, revise control measures implemented so as to maintain, so far as is reasonably practicable, a work environment that is without risks to health or safety.

A duty holder must review a control measure if:

- the control measure does not control the risk it was implemented to control so far as is reasonably practicable (for example the results of monitoring show that the control measure does not control the risk or a notifiable incident occurs because of the risk)
- before a change at the workplace that is likely to give rise to a new or different risk to health or safety that the measure may not effectively control (for example a change to the workplace itself or any aspect of the work environment or a change to a system of work, a process or a procedure)
- a new relevant hazard or risk is identified
- the results of consultation by the duty holder under the Act or this regulation indicate that a review is necessary
- a health and safety representative requests the review in accordance with the regulation.

4.1 Risk controls in common tunnelling methods and activities

The common hazards and potential risk areas in most tunnels under construction relate to the confines of working underground, including:

- tunnel stability – rock or earth falls and rock or gas outbursts
- changing conditions – strata and stress fluctuations
- limited space and access
- level of expertise (even long-term tunnellers may lack experience in certain specialised aspects or methods)
- air contamination or oxygen depletion
- fire or explosion
- the use and maintenance of fixed and mobile plant
- traffic management
- close proximity to electrical supplies and circuits
- compressed air use and high pressure hydraulics
- projected particles from rock breaking, drilling or cutting
- manual tasks
- large scale materials handling, spoil out, and materials and equipment
- uneven surfaces
- wet or other slippery surfaces
- heights
- falling objects
- overhead seepage, ground and process water
- ground gas and water inrush
- contaminated groundwater
- reduced visibility
- loss of power, including lighting and ventilation
- noise levels
- vibration
- heat and humidity
- crystalline silica
- blasting fumes
- flammable gases and vapours
- combustion gases including diesel particulate matter

- production of vapours during the use of rock bolting bonding agents, and
- hazardous chemicals.

The systems of work and control measures selected are generally determined by individual job factors identified in the consultation and risk assessment process. Table 1 outlines examples of specific hazards, risks and control measures in common tunnelling and excavation activities.

Table 1: Hazards and risks associated with common tunnelling and excavation activities

Common tunnelling and excavation activities	
Examples of specific hazards or risks	**Example risk control measures**
Rock falls	More frequent inspection and scaling Mechanical scaling and bolting Mark out bolting pattern by laser survey Timely installation of ground support Change ground support methods/density Overhead protection while installing ground support manually
Failure of floor or roadway	Concrete the floor/roadway
High water inflow	Grout old drill holes Injection grouting ahead of the face Probe drill and drain Pumping from surface bores
Scaling	Mechanical equipment Work from elevating work platform basket Overhead protection
Gas inrush	Probe drill hazard areas through check valves Wet drilling and gas monitoring Increased face extraction ventilation
Falls from height	Maintenance platforms with guardrails Fall-arrest PPE
Loss of lighting	Emergency lighting and cap lamps
Moving plant	Planned vehicle movement procedures Isolate moving plant from pedestrians Operator to ensure clear path before moving Stop plant, pedestrians to walk past Restrict access Provide lighting
Manual tasks (e.g. handling air tools, drill rods, supports, cutters, grout)	Engineering assessment of tasks Use mechanical equipment with automatic feed Use lifting aids Team lifting Select lightweight rock drills, smaller bags Use vibration insulation on handles
Heat stress See Appendix 5	Increase ventilation More frequent rests and cool water Cool suits Reduce use of high heat output equipment
Noise	Insulate plant Hearing protection
Dust	Increase face extraction ventilation Water sprays on cutting equipment or over

	muck heaps and spoil conveyors

4.1.1 Excavation methods

The site investigation, including geotechnical investigations and risk assessment, the tunnel design, access limitations and other local factors should be used to establish the appropriate excavation methods. A number of different excavation methods could be used on a single project.

The tunnel design will usually adopt particular excavation and support methods, but other methods may be used, provided they do not compromise tunnel safety. The methods of excavation should not only allow the designed ground support to be installed as planned, but also allow for the installation of additional ground support if ground conditions are found to be worse than considered in the design or during the actual excavation work.

To determine appropriate excavation methods, consider the following:

- the tunnel design, including the dimensions, shape, excavation tolerance of the excavation, and the tunnel support and lining design
- timeframes for excavation work
- the expertise of the contractors
- tunnelling machinery specified
- available access
- the nature of the ground (e.g. reclaimed ground)
- the water table level
- historical excavation experience in the area under similar conditions
- the possibility of flooding from:
  - surface run-off, tidal water, rivers, dams, reservoirs, lakes or swamps
  - leaking stormwater drains, water mains or flooded communications conduits
  - intersection of old flooded workings or an underground water-bearing structure, such as a fault, cast or perched water table
- the proximity of existing underground services, such as water mains, sewerage drainage, electricity, gas and telephone
- soil nails, rock anchors, basement underpinning, or other pre-existing ground support;
- adjacent excavations (e.g. shafts, tunnels or trenches)
- other hazards, either natural or man-made, such as:
  - heavy loadings, above or adjacent to the tunnel (e.g. roadways, railway lines, buildings)
  - rivers or planned or existing spoil stockpiles
  - chemical contamination (e.g. from past dumping, leaking tanks or pipes or natural deposits)
  - the presence of methane, or other hazardous or flammable gases and vapours (e.g. where coal seams are present or vegetation has decayed in the soil or hydrocarbon contamination from historical fuel leaks exist), and
- dynamic loads or ground vibration near an excavation, including:
  - traffic (highway or rail)
  - excavation equipment
  - explosives.
- dust production and dust control measures.
- airborne contaminants

Note: It is common for mud and water to build up in certain areas within tunnels; typically this occurs where there is significant inflow of ground water or where water can not be readily or adequately drained. A risk assessment should determine the maximum height underground workers are required to work in (e.g. less than booth height).

Note: when unexpected hazards are encountered (such as the presence of an unidentified coal seam) then the excavation methods, safety management plan, monitoring and control measures need to be reviewed, and if necessary revised, prior to work being allowed to continue. If you are tunnelling through coal you will need flameproof equipment.

4.1.1.1 Hand excavation

Most tunnelling operations are totally mechanised, or at least to a considerable extent. The use of hand excavation is generally limited to small sections of work within larger projects (e.g. a small shaft, sump or drive-in area with limited access and limited possibility for mechanisation).

Hazard areas that should be considered in hand excavation include:
- manual tasks (e.g. additional physical lifting and activity)
- falls from heights (e.g. non-mechanised access)
- falling objects (e.g. proximity to the worked face)
- vibration effects on the body from the use of hand tools (e.g. rock drills or jack picks)
- noise (e.g. proximity to air tools and drills)
- dust (e.g. closer proximity to the face)
- heat stress (e.g. due to physical exertion, and
- crush injuries from small mobile plant.

Note: Air environment in a confined space is covered in section 4.5.7 - Heat stress (see Appendix 5).

4.1.1.2 Machine excavation

Because most tunnelling excavation is mechanised, the implications of using plant causes significant hazards and risks that must be identified and controlled (see 4.4).

The hazard areas that should be considered in machine excavation include:
- moving plant and moving components on plant (e.g. crush, nip or shear)
- height (e.g. elevated areas of plant, including service access points)
- restricted operator visibility and communication (e.g. machinery obstructing view, loud continuous noises)
- ergonomics - visibility, seat belts, hand rails, seating, vibration controls, stairs, manual tasks
- locking and security mechanisms, including power isolation
- fire (e.g. flammable liquids and materials)
- high pressure liquids or gases
- heat (e.g. burns from localised heat sources or heat exhaustion from general heat)
- air contamination (e.g. from excavation dust or exhaust emissions), and
- radiation from lasers (see 4.5.13.1).

4.1.1.3 Drill and blast methods

Drill and blast methods for tunnel construction are not widely used with the continued evolution of excavation methods, and the environmental impact constraints inherent with many tunnel locations. Issues around explosives are referred to in the *Explosives Act 1999*, under the jurisdiction of the Department of Mines and Energy (see Appendix 2 for other sources).

For shorter tunnels, or where ground conditions are very hard, drill and blast methods are often the only alternative. This method has particular hazards that require a number of control measures to manage the associated risks.

The hazard areas to be considered in the assessment and control of risks include:

- storage, transport and use of explosives
- ground support requirements
- ground vibrations, overpressures from blasting and fly rock
- competence of explosives contractors and operators
- the effect on surrounding strata
- drilling of faces
- firing times and preventing access to firing areas, and
- clearance of blasting fumes and dust.

If explosives are to be stored, used and handled at a tunnel construction site, the activities must be licensed under the *Explosives Act 1999*. The PCBU or the principal contractor are equally responsible for the control, safe and secure storage, use and handling of the explosives.

The Chief Inspector of explosives must be notified of any blasting seven days before operations commence. Any incident involving the explosives or the blasting operations must be immediately reported to the Chief Inspector of explosives in accordance with the *Explosives Act 1999*.

Guidance on the safe handling of explosives can be found in *AS 2187 Explosives – Storage, transport series*. This standard provides details on methods of safe storage, transport and use. Site procedures and work methods for controlling the handling of explosives must comply with this standard (e.g. when storing explosives, detonators must never be stored in the same magazine as other explosives).

Where drill and blast operations are to be used, specific safe work method statements must be developed containing enough detail to cover the complete work process.

4.1.2 Portal protection

Before tunnelling commences, portal entries that are not constructed in a permanent manner (e.g. final concrete structure is not in place), will require support and protection from vehicular traffic.
This support will vary but should, at a minimum, include:

- ground support of the high wall, if any, above the portal entrance
- support of the portal brow or lip, and

- protection at the portal, protruding sufficiently out from the tunnel to protect people entering or leaving the tunnel from material that might be dislodged off the high wall above the portal entrance.

A fence or other barricade should be provided above the portal to retain people and objects if there is access or work being carried out above the portal.

4.1.3 Inspections and scaling

Inspection of the roof and walls, and scaling of loose rock, should be conducted immediately after excavation.
As the effects of time can cause deterioration to rock surfaces, periodic follow up inspections and scaling should be conducted on unlined tunnel areas.
A risk assessment, with ongoing revision based on the inspection results, should be used to determine an appropriate period for initial and regular inspection and scaling.

At shift changes, there should be a handover discussion to pass on information on the status of inspection and scaling, including the areas not yet inspected, and the location of any identified drummy ground still in need of support.

Scaling should take place:

- for drill and blast excavation:
  - after every blast when the face, roof and wall areas and spoil heap have been washed down, and
- for other excavation methods:
  - at intervals as determined by the risk assessment
  - during the support cycle if more loose rock is revealed and as the support installation moves forward from supported ground
  - whenever the inspection reveals the possibility of loose rock on any wall or roof.

The excavation should be thoroughly washed down before the initial inspection. Regular inspections should continue in the unlined tunnel areas, to a schedule determined by the risk assessment.

Inspections and scaling should be conducted from supported and scaled areas. Where practical, machine scaling is preferred to hand scaling. Where hand scaling is used it should be from an elevated work platform (basket).

Drummy ground that can not be scaled down should have additional support installed. Particular attention should be taken at breakthroughs, as the previous excavation and associated stress changes may have weakened the ground. Where drummy ground is to be supported, mechanical means should be adopted to remove the need for workers to work under unsupported ground.

4.1.4 Ground support controls

Most tunnels require some form of permanent ground support. The permanent lining can be installed directly as the excavation progresses, or temporary support installed initially, followed by a permanent lining. This may be followed by the installation of a non-structural secondary lining.

Additional ground support or overhead protection may be required to provide protection during the construction phase. It is usual for the planned ground support to vary throughout the project as the tunnel dimensions or ground conditions vary, and the locations of changes should be included in the design documentation.

The support actually installed as a tunnel progresses will often alter with exposure. This alteration may be due to assessment of the actual ground conditions and experience gained from the monitoring of the performance of the supports.

Installing ground support should be conducted from supported areas or using equipment which provides overhead protection for the operator or installer. Where this is not possible, control measures should be implemented to avoid ground or materials (e.g. shotcrete) falling on people.

The ground conditions should be inspected as the excavation progresses, in accordance with the inspection plan outlined in section 2.2.6.

Risks from falling objects, including falling shotcrete, should be controlled by providing effective barricading to prevent people from accessing high risk areas. The potential of serious injuries arising from fallen shotcrete is equal to falling rock.

The results from the ground and tunnel support system inspections need to be assessed, and if ground conditions deteriorate or are not performing according to the original design, the existing ground support controls may need to be changed. Also, changes could be made if the ground conditions are better than allowed for in the design.

Inspection and assessment of the performance of the support system and any necessary changes to the specification should be carried out by a competent person. Each ground support method or type has its own hazards and risks attached to the installation process, which need to be controlled.

4.2 Risk controls in specialist construction methods and activities

Both specialist and common construction methods require safe systems of work and the implementation of appropriate control measures. The system of work and the control measures selected should be determined by considering individual job factors identified in the consultation and risk assessment process. Designers and PCBUs should participate as a fundamental part of the risk management process.

The following sections describe some of the specialist construction methods and activities and provide examples of relevant specific hazards, risks and control measures that should be considered in addition to the common hazards, risks and control measures.

Note: Refer to section 2.1.2 - Responsibilities of duty holders.

4.2.1 Shaft sinking

Shafts vary greatly in construction technique depending on conditions and their purpose, and may be vertical or inclined, lined or unlined, of various shapes, and excavated using various techniques.

Shaft sinking involves excavating a shaft from the top, with access and spoil removal from the top.
Specific hazards and risks include:

- shaft dimensions limit clearance
- condition of hoisting equipment (e.g. winch, ropes and hooks)
- falls from heights
- falling objects, including fine material and water from shaft wall
- hoisting and winching people, materials, spoil and plant
- working platforms or material kibbles hang up
- communications
- dewatering
- ventilation, and
- emergency egress.

Control measures include:

- guiding the working platforms and kibbles
- lining the shaft early
- avoiding overfilling kibbles
- cleaning the underside of kibbles before lifting
- closing shaft doors before tipping, and
- cleaning the spillage off doors, stage and any steelwork.

4.2.2 Raise boring

Raise boring is a method of constructing a shaft (or raise) where underground access has already been established. Raised bored shafts can be from the surface or from one horizon to another underground. The method is remote and does not require people to enter the shaft. The method involves:

- installing a raise borer rig at the top of the planned raise, above the existing tunnel (or other underground excavation)
- drilling a pilot hole down into the tunnel
- attaching a reaming head and back reaming to the rig to create the raise, and
- supporting the completed hole, if it is required (e.g. by lining or installing ground support).

Specific hazards and risks include:

- poor surface materials for rig set up
- breakthrough causes unexpected rock fall
- rock fall if the breakthrough area is not secured before bit removal
- manual tasks problems with bit removal and reamer head attachment
- spoil ‘mud rush’ after a hang up
- falling into the shaft when removing reamer head or rig
- working platforms or material kibbles hang up

- communications
- dewatering
- ventilation
- dust, and
- emergency egress.

Control measures include:
- barricading the breakthrough area to prevent access well before breakthrough
- coordinating the spoil clearance to reduce the likelihood of hang ups or falling material entering the tunnel
- monitoring the spoil flow and stop reaming if hang up occurs to reduce potential mud rush, and
- extracting and suppressing the dust using water sprays and ventilation.

4.2.3 Raised shafts and excavations

From underground access, a raised or a vertical or sub-vertical excavation may be required to the surface or to another horizon. Certain methods are available, including:
- blind methods where no top access is available, such as:
  - conventional or ladder raise, now largely obsolete for vertical raises, may have application for some inclined excavations
  - *Alimak* or raise climber working off rail segments, and
  - shrink method for short excavations working off broken spoil
- other methods where top access is available, such as:
  - cage or gig rise using a moving cage/platform hoisted through a rope in a pilot hole
  - long-hole rise (using drill and blast), and
  - underhand benching or rise stripping.

Specific hazards and risks include:
- working and accessing from below the excavated face, which may not have been inspected and scaled
- working upwards — material enters the eyes
- falling objects, and fine material and water from the shaft wall
- communications
- ventilation is more difficult, and
- isolation, emergency, access and egress issues.

Control measures include:
- providing access using a two-level cage, with the top level providing overhead protection when not at the face
- drilling a large diameter pilot hole for the cage rope and establishing ventilation up the hole
- barricading the bottom area and limiting access to the authorised people, and
- barricading and restricting access to the breakthrough area well before breakthrough.

4.2.4 Pipe jacking

The pipe jacking method is mostly used in soft tunnelling conditions. The tunnel is lined with a pipe that is installed in sections, pushed or jacked into the increasing tunnel length from the portal. It consists of a typical sequence where:

- A jacking pit is excavated, supported and reinforced to resist the jacking forces.
- The excavation of a small section of tunnel takes place ahead of a leading pipe.
- The continuous line of pipe sections is jacked by hand or machine into position, pushing the leading pipe up to the face.
- The face is excavated and the pipe pushed further, adding sections at the rear as space permits.

The support and lining is provided by the pipe. Some face support may be required in extreme conditions.

Specific hazards and risks include:

- restricted access and dimensions, including the pipe-positioning area
- jacking operation and jacking forces
- soft material, which leads to face failure
- water or liquefied soil or mud inflow
- pipe binds, leaving face and excavated section exposed for longer than planned, and
- visibility.

Control measures include:

- using mechanical rather than manual lifting where possible
- locating jack power pack away from work area in the pit
- supporting the face during jacking
- dewatering or grouting to reduce water inflow
- lubricating pipes or installing intermediate jacking stations in longer tunnels
- disallowing workers to work under suspended loads, and
- lighting.

4.2.5 Caissons

The caisson method is used to sink shafts in very soft or wet ground conditions. The method is suitable for shafts generally larger than bored shafts.
The caisson method involves:

- stacking concrete (or steel) sections on each other at the surface, the lower or leading section having a cutting edge, and
- excavation of the shaft bottom undercuts the edge of the leading caisson and the sections move downward together under their own weight, or are driven down.

The shaft remains fully supported and lined for its entire length.

Caissons may be pressurised in certain circumstances with compressed air to provide temporary ground support and reduce water ingress at the shaft bottom. Requirements and controls applicable to working in a pressurised atmosphere with this method can be found in *AS 4774.1 - Work in compressed air and hyperbaric facilities – Part 1: Work in tunnels, shafts and caissons.*

4.2.6 Ground freezing

Ground freezing is used to sink shafts in very soft and wet ground conditions and where there are free running saturated sands. This method is used more commonly in Europe because of the ground conditions, but rarely in Australia.

The wet ground where the shaft is to be sunk is artificially frozen, excavated as though it were solid rock, then lined and sealed before being allowed to thaw. The process can also be applied to horizontal development.

The additional hazards stem from the reduced temperature and include:
- the effect of cold on people and equipment
- spoil removal (it may melt or resolidify depending on the ambient temperature)
- the risk of collapse from localised or general thawing.

Control measures include:
- warm clothing, job rotation and rest periods
- heated operators' cabins and rest areas
- temperature and refrigeration plant monitoring, and
- excavation and spoil-removal equipment adapted for cold operation.

4.2.7 Compressed air tunnelling

A compressed air atmosphere is not commonly used in tunnelling in Australia, but may be used when tunnelling under rivers or through highly saturated ground.

This method is used to provide additional temporary ground support in very soft and extremely wet ground conditions, and where other means of preventing excessive ingress of water or the collapse of ground into the tunnel, are not practical. The pneumatic support process involves:
- providing a bulkhead with air locks for access into the tunnel, and
- pressurising the tunnel with compressed air to hold back the water and weak strata.

Additional requirements and controls applicable to working in a pressurised atmosphere can be found in *AS 4774.1 – Work in compressed air and hyperbaric facilities – Part 1: Work in tunnels, shafts and caissons.*

4.2.8 Pressure grouting

Pressure grouting involves pumping a grout (e.g. cement slurry or chemical grout), under pressure into a void or porous ground. Pressure grouting:
- fills voids behind a tunnel or shaft lining to increase the integrity and strength of the lining or to reduce water inflow
- stops or reduces direct water inflows into the excavation, and
- improves ground conditions by cementing unstable areas.

Before implementing a pressure grouting program, the PCBU should review risk assessments and control measures adopted to manage the risks.

Specific hazards and risks include:
- cement or chemical grout dust
- eye or skin contact with grout, which causes chemical burns, poisoning and other toxic effects
- fracturing of the ground
- damage to nearby services, buildings or structures, and

- high pressure hoses and connections.

Control measures include:
- a documented grout plan listing specified grout pressures and patterns
- an easy to read pressure gauge to assist in reducing the risk of exceeding specified grout pressure
- washing and eyewash facilities at the grout site, and
- PPE, such as gloves and full face eye shields.

4.3 Air quality and ventilation systems

A duty holder must ensure, so far as is reasonably practicable, that ventilation enables workers to carry out work without risk to health and safety and that workers carrying out work in extremes of heat or cold are able to carry out work without risk to health and safety.

A duty holder 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. Where a non-standard work roster is employed (i.e. a roster that is not 5 x 8 hour shifts each 7 calendar days) then the exposure standard must be adjusted to suit the hours of work. The exposure levels can be found in Safework Australia's *Workplace Exposure Standards for Airborne Contaminants* or at safeworkaustralia.gov.au

The PCBU should ensure that:

(a) mechanical ventilation, appropriate for the work being carried out, is used to control atmospheric contaminants, and that the ventilation is maintained regularly, and

(b) if a mechanical ventilation system is used to control exposure to a contaminant, the system:
  - (i) is located as close as is practicable to the source of the contaminant to minimise the risk of inhalation by a person at work
  - (ii) is used for as long as the contaminant is present
  - (iii) is kept free from accumulations of dust, fibre and other waste materials and is maintained regularly
  - (iv) if the system is provided to control contaminants arising from flammable or combustible substances—is designed and constructed so as to prevent the occurrence of fire or explosion, and

(c) if a ducted ventilation system is used, an inspection point is fitted at any place where blockages in the ventilation system are likely to occur.

Tunnels are usually at risk of atmospheric contamination because:
- excavations can be a receptacle for gases and fumes that are heavier than air
- gases and fumes can seep into the tunnel, particularly when other work is taking place nearby (e.g. gases, such as methane and sulphur dioxide, engine fumes, such as carbon monoxide and carbon dioxide, and leakage from gas bottles, fuel tanks, sewers, drains, gas pipes and LPG tanks)
- oxygen in a non-ventilated area can be depleted due to internal combustion plants, oxidation or other natural processes
- most flammable gases and fumes and certain dusts, such as coal and sulphide, can be ignited if not sufficiently diluted
- dust and fumes in the air can cause acute symptoms of respiratory infarctions, as well as chronic disease, and reduce visibility

- blasting activities
- hazardous contaminants can arise from tunnelling activities, and
- heat and humidity can reach hazardous levels.

These hazards can also be encountered in excavations for foundations, bored and drilled pier holes, shafts, drives, pits and trenches. The detrimental effects of inadequate ventilation can be short-term, or cumulative and long-term.

A mechanical ventilation system to ensure that sufficient oxygen is available for respiration (from fresh air), and dilutes and transports harmful atmospheric contaminants away from work areas, should be used.

The air flow needs to be sufficient to control contaminants to provide a clean and safe atmosphere for work, and adequate cooling for people working in warm and humid environments.

The ventilation requirements should be determined by doing a risk assessment, which will account for difficult to control contaminants, such as silica.

The consequences of poor ventilation include:

- heat exhaustion where temperatures are excessive;
- exposure to fumes, substances or mixtures, which can lead to unconsciousness, longer-term health problems and disease and even death;
- exposure to excessive levels of diesel particulates, which can lead to health issues such as lung damage; and
- fatigue and impaired judgment.

A duty holder involved in tunnelling work must ensure that ventilating air is provided in sufficient volume, velocity and quantity to:

- remove any atmospheric contaminants; and
- maintain a healthy atmosphere in workplaces.

Ventilation design should ensure there are no dead spots, low air speed areas, flow reversals, dust concentration or recirculation. To address the adverse effects of poor ventilation an air velocity of not less than 0.5 metres per second (m/s) of uncontaminated air should be provided in all tunnel sections averaged across the full open section.

The arduous and changing nature of tunnelling means there should be:

- an adequately designed ventilation system that is capable of supplying all the necessary ventilation quantity requirements by supplying sufficient air flow to all those underground areas at all times when people are present throughout the construction
- regular monitoring of air flows and the atmosphere
- ongoing and effective maintenance of the ventilation system, including promptly repairing all leaks, maintaining rigid and flexible ducts, barricades and fans
- a regularly advanced and upgraded ventilation system, resulting from the monitoring program, to ensure that sufficient air flows are always maintained
- unauthorised entry signs for areas without adequate ventilation
- adequate re-entry times after blasting, and adequate re-entry testing procedures
- specific controls and monitoring of explosive gases

- constant monitoring and control of the sources of contaminants (e.g. reduce diesel emissions, block boreholes and store materials on the surface), and
- personal, or machine-mounted, continuous monitoring devices that sound an alarm when dangerous gas levels, or oxygen depletion, are detected.

4.3.1 Monitoring air quality

A person conducting a business or undertaking at a workplace must ensure that air monitoring is carried out to determine the airborne concentration of a substance or mixture at the workplace to which an exposure standard applies if:

(a) the person is not certain on reasonable grounds whether or not the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure standard; or
(b) monitoring is necessary to determine whether there is a risk to health.

A person conducting a business or undertaking at a workplace must manage risks to health and safety associated with a hazardous atmosphere at the workplace. An atmosphere is a ***hazardous atmosphere*** if:

(a) the atmosphere does not have a minimum oxygen content in air of 19·5% by volume under normal atmospheric pressure and a maximum oxygen content of air of 23·5% by volume under normal atmospheric pressure; or
(b) the concentration of oxygen in the atmosphere increases the fire risk; or
(c) the concentration of flammable gas, vapour, mist, or fumes exceeds 5% of the lower explosive limit for the gas, vapour, mist or fumes; or
(d) a hazardous chemical in the form of a combustible dust is present in a quantity and form that would result in a hazardous area.

A person conducting a business or undertaking at a workplace should also manage risks to health and safety associated with all other toxic gases or aerosols.

The risk assessment process must be used to:

- determine the engineering controls, work practices and on-site atmospheric or biological monitoring required, and
- determine the monitoring program for airborne contaminants, such as dust and fumes, including taking air samples and ensuring the relevant exposure standard is not exceeded or that people are not exposed to a hazardous atmosphere.

Daily tests should be carried out before work starts, with continued monitoring throughout the work period. The work should be examined by competent persons using appropriate detection and measuring equipment.

The monitoring should include air testing for:

- flammable fumes or gases
- oxygen deficiency (e.g. presence of asphyxiant gases)
- temperature and humidity, and
- airborne contaminants (e.g. toxic gases, fumes or respirable dusts).

The principal contractor should ensure that:

(a) air monitoring is undertaken in accordance with a suitable procedure, and
(b) the results of the air monitoring are recorded, and
(c) any worker or other person who may be or may have been exposed to an atmospheric contaminant that has been monitored is provided with the results of the monitoring, and

(d) the air monitoring records are readily accessible to any worker or person.

The PCBU must ensure that exposure to an airborne concentration of a contaminant classified as a hazardous chemical is not at a level greater than the exposure standard. Current exposure standards can be found in Safework Australia's *Workplace Exposure Standards for Airborne Contaminants* or the Hazardous Substances Information System (HSIS) at safeworkaustralia.gov.au. Where a non-standard work roster is employed, then the exposure standard must be adjusted to suit the hours of work.

4.3.2 Hazardous contaminants

People may be exposed to hazardous contaminants by inhaling, swallowing, or absorbing by contact with the skin or the eyes. Hazardous contaminants can present a physical or chemical risk to human health. Due to the nature of working in a tunnel, contaminants generated in one area of the tunnel will transfer readily to other areas. Protection against airborne hazards should encompass all appropriate workers, not just the ones creating the hazard.

Hazardous contaminants include:

- silica dust, refractory ceramic or other mineral fibres, diesel particulate material
- toxic gases, fumes, vapours and other toxic chemicals
- explosive and asphyxiant gases, and
- hazardous wastes.

Biologically active substances and micro-organisms are not hazardous contaminants and are not normally found in tunnelling work, unless a sewer line is accidentally ruptured. If this happens, personal hygiene precautions, such as washing hands with soap and water before eating, smoking or drinking, should be taken and open wounds covered. Additional biological risk could be introduced via the ventilation system and should be controlled.

Hazardous contaminants can:

- arise from the mechanical process of tunnelling (e.g. drilling or cutting) or existing excavations (e.g. silica dust)
- be produced in situ (e.g. exhaust gases from internal combustion engines, welding or shotcreting) or from blasting activity (e.g. carbon monoxide), and
- be introduced into the tunnel from the external environment (e.g. liquid fuels or chemicals).

Common source activities for harmful airborne hazardous contaminants are contained in Table 2.

Table 2: Hazardous contaminants

Activity	Contaminant	Harmful component
Hot work	Welding/cutting fumes	Metal oxides, oxides of nitrogen, ozone, fluorides.
Operation of internal combustion engines	Exhaust fumes	Carbon monoxide, carbon dioxide, diesel and other particulates, oxides of nitrogen, fuel vapours, aldehydes and hydrogen sulphide. Oxygen depletion can occur.
Tunnelling	Rock dust	Chrystalline silica and other mineral dusts, including coal dust.

Shotcreting, rock bolting, concreting, grouting	Cement dust/accelerator	Cement dust, ammonia and chemical accelerating compounds.
Battery charging	Vapours	Flammable gas, acid fumes.
Shot firing	Blasting fumes	Chrystalline silica dust, ammonia, oxides of nitrogen, carbon monoxide, sulphur dioxide, carbon dioxide.

The regulation requires PCBUs to make sure that no one is exposed to an airborne concentration of atmospheric contaminants above the exposure standards. The exposure levels can be found in Safework Australia's *Workplace Exposure Standards for Airborne Contaminants* or at safeworkaustralia.gov.au

An approximate guide to the effects and consequences of some common airborne contaminants at various concentrations is provided in Table 3. The applicable exposure standards can be found in the 'Hazardous Substances Information System' (HSIS) at safeworkaustralia.gov.au.

Table 3: Common contaminants

Common contaminants	**Range of typical effects at increasing levels of exposure above acceptable limits**
Carbon dioxide	Increased depth of breathing within 15 mins of exposure.
	Feeling of inability to breathe, headache, dizziness, sweating and disorientation.
	Nausea, strangling sensation, stupor and loss of consciousness within 15 mins. Many deaths reported from exposure above 20 per cent.
Carbon monoxide	Headache within a few minutes. Possibility of collapse in half hour, coma in 1 hour and possible death in 1.5 hours.
Hydrogen sulphide	Initial eye irritation, then loss of sense of smell.
	Rapid breathing, respiratory arrest, collapse, death.
	Immediate collapse and respiratory paralysis, death.
Nitrogen dioxide	Considered dangerous for short-term exposure. Moderately irritating to eyes and nose.
	Fatal within 30 mins. Death is due to fluid build up in lungs (pulmonary oedema) leading to asphyxia.
Sulphur dioxide	Irritation of the eyes, nose and throat, choking and coughing within 5 to 15 minutes.
	Immediately dangerous.
	A 10 minute exposure has been fatal at high concentration.
Chrystalline silica dust	Cumulative exposure leads to lung damage/disease (silicosis and chrystalline silica is a carcinogen).
	Can occur after 15 to 20 years of moderate to low exposure, or after a few months of very high exposure.
	Death can occur from respiratory failure.
Non contaminants	
Oxygen depletion	
Oxygen	Normal atmosphere.
	Rate of respiration increased.

	Fatigue on exertion, disturbed respiration.
	Nausea, inability to move freely, collapse.
	Respiration stops, heart stops within a few minutes.

4.3.2.1 Dusts and silica

Dust in tunnel construction needs to be controlled. Airborne respirable dust particles particles (as defined in AS 2985 - Workplace atmospheres - Method for sampling and gravimetric determination of respirable dust) are too fine to be filtered by the nasal cavity and can be inhaled, or respired, deep into the lungs. Long-term exposure to respirable[3] dusts can lead to diseases ranging from bronchitis to various cancers. Even if the dust is not at harmful levels or sizes, it can increase the risk of physical injury or harm because of the reduced visibility and irritation to the eyes and throat.

Non-hazardous nuisance dust can be generated about the site or underground by dry roadways, bare soil or rock, vegetation removal, traffic and the wind.

Silica is the most common hazardous dust particle found in tunnelling. The risk assessment of the tunnel construction should consider the presence of silica and the likely generation of dust containing silica.

Respirable crystalline silica (quartz) is a common mineral present in sandstone, clay, granite and many other rocks as well as in the overburden and spoil. Exposure to respirable crystalline silica is known to cause silicosis, a respiratory lung disease that can be fatal.

Mineral dust can be generated and released into the atmosphere during the tunnelling operation when:

- rock or concrete is broken, drilled, cut or blasted, or wherever ground is disturbed
- rock cutting with road headers or tunnel boring machines (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 traffic, and
- muck piles dry out.

All possible sources of the generation of dust in a tunnel should be identified and control measures selected to eliminate or minimise the generation of the dust at the source.

Control measures for harmful airborne substances include:

- designing, using and maintaining an exhaust ventilation system
- maintaining extraction at, or close to, the point of generation (e.g. use of brattice curtains or half-curtains to reduce dust roll-back)
- using extractors or dust collection devices in-line, near the face
- increasing the extraction rate (ventilation capacity) when and where required
- wet spraying, to suppress dust at the point of generation (e.g. at drop points on conveyors)
- adding surfactant (detergent) to dust suppression water

[3] Small enough to be inhaled.

- using tools fitted with dust extraction or water attachments
- wet drilling
- installing water applicators onto the machinery, rather than using hand-held applicators
- wetting muck piles, spoil conveyors and roadways
- spraying water over spoil heaps after blasting and while loading
- limiting exposure times to dust
- providing PPE (e.g. respirators rated for concentration and duration of exposure)
- enclosed cabins with windows closed at all times
- wet cleaning of cabins and crib rooms regularly
- fitting air filtering systems to the air conditioning units of front end loaders, excavators and other machinery
- keeping personnel vehicles dust sealed and pressurised, and
- assessing and controlling the risk of cross contamination between worksites, work processes or workers' clothing.

Examine how workers' clothes are cleaned at the end of each shift. Roadheader operators in particular will have dust-saturated clothing. Unless it can be demonstrated that dust on clothing in this system is not a mechanism for the spread of silica around the work site, or off-site, or contributing to individual doses, contaminated clothing should be washed daily in an approved manner. Cleaning of people and plant should never been undertaken using compressed air blow-down.

4.3.2.2 Use of repiratory protection to control dust exposures

Where higher order controls fail to control hazardous chemical, particularly respirable dust, exposures, and resort is made to the low order control of PPE, the PCBU should ensure any respirators supplied are capable of preventing people inhaling hazardous dust or other airborne contaminants at the concentration and duration of the exposure. Guidance on the selection, use and maintenance of respirators can be found in *AS/NZS 1715 – Selection, use and maintenance of respiratory protective devices.*

Workers exposed to crystalline silica dust in excess of the exposure standard will require health monitoring (see 4.5.2.1 – Health monitoring for hazardous chemicals).

4.3.2.3 Diesel emissions

Internal combustion engines, other than diesel, are not to be used underground. The exhaust emissions from diesel engines can be a major source of contamination and oxygen depletion to a tunnel atmosphere. This should be considered in the plant selection, and in the design, operation and monitoring of the ventilation system.

Where diesel engines are used, the tunnel ventilation should be monitored by testing the tunnel air for the products and effects of diesel engines, such as:

- oxygen deficiency and presence of asphyxiant gases such as carbon monoxide, and
- airborne contaminants, such as toxic gases and fumes.

A duty holder should achieve the underground work industry best practice exposure standard of 0.1mg/m^3 for submicron diesel particulate matter measured as Elemental Carbon to minimise the irritant effects of exposure.

Also, the performance of diesel engines should be tested at the exhaust before being approved by management for underground use, then at three monthly intervals after being put into service, to determine that the emissions of carbon monoxide, carbon dioxide and nitrogen oxides are below the appropriate limits.

Where diesel engines are used underground, they should have exhaust conditioners, such as water baths (scrubbers) or catalytic converters installed and maintained, as well as dilution and extraction provided by the ventilation system.

Generally, catalytic converters are most suited to large engines used for heavy workload conditions, such as materials handling. Catalytic converters need cleaning, or replacing, at intervals recommended by manufacturers.

Smaller engines, and those subject to intermittent running, such as service vehicles, are more suited to water bath type exhaust conditioners, which require regular, often daily filling up to remain operational. Low level shut down devices may be installed to stop operation before the conditioner becomes ineffective.

Plant congestion in an area may cause excessive emission levels. Risk assessments can be used to identify these areas and the maximum emissions.

Emission levels should be monitored through full load exhaust gas testing on the plant, and by testing the diluted tunnel atmosphere. The contaminants (e.g. Diesel Particulate Matter – DPM) should be monitored and controlled.

4.3.3 Managing heat stress

The PCBUs must ensure that:

- adequate ventilation and air movement is provided in enclosed environments that may become hot, and
- appropriate work and rest regimes, relating to the physical fitness, general health, medication taken and body weight of each worker exposed to heat, are implemented.

To determine the level of heat-related risks for a worker, assess the following factors:

- environmental conditions (e.g. air temperature, radiant heat, humidity, air flow)
- physical work (e.g. strenuous or light)
- work organisation (e.g. the duration, exposure to heat, time of day), and
- PPE and clothing (e.g. heavy protective clothing).

A combination of these conditions can cause heat stress or heat stroke and the effects can range from simple discomfort to life-threatening illnesses. Heat stress reduces work capacity and efficiency. Signs of heat stress include:

- tiredness
- irritability
- clammy skin
- confusion
- light-headedness
- inattention
- muscular cramps.

Signs of heat stroke include:
- high body temperature
- no sweating
- hot and dry skin
- confusion
- loss of consciousness and convulsions.

Conditions of high wet bulb temperatures and low air velocities give little cooling effect. Because of variability in environmental and work conditions, the potential for heat stress should be assessed by using the Basic Thermal Risk Assessment as described in the AIOH Heat Stress Standard[4].

Control measures for preventing heat stress include:
- providing adequate ventilation
- undertaking a risk assessment and determining a monitoring regime
- reducing items of heat-producing equipment in the tunnel
- monitoring air velocity and wet bulb temperature regularly, determining cooling effect, assessing and recording results
- regulating air flow, or modifying ventilation, to ensure adequate cooling
- refrigerating the air supply in extreme conditions
- providing additional ventilation fans to create air flows in low-flow areas
- rotating people in hot areas
- providing rest breaks in cool environments
- providing chiller vests
- educating people to recognise symptoms of heat stress
- providing cool drinking water – current industry practice suggests workers drink half a litre of water each hour when hot environments cause excessive sweating, and
- providing PPE for surface heat exposure (e.g. shade, hats).

(See Appendix 5 for more information on heat stress).

4.4 Plant-related risks

Tunnelling operations invariably involve a variety of plant including plant that may be hand held, fixed, rubber-tyred, tracked or rail mounted and powered electrically, by diesel engine or compressed air. Internal combustion engines other than diesel should not be used underground.

Because of the confines of underground work and other factors, including visibility, noise, congestion, roadway conditions and pedestrian traffic, there are many and varied risks to be assessed and controlled in relation to plant design, selection, use and maintenance.

4.4.1 General plant information

Plant is the term used for all machinery, tools, appliances and equipment. Regulatory requirements include:
- provisions for prescribed occupations, and

[4] AIOH is the Australian Institute of Occupational Hygienists.

- a registration system for certain plant designs and plant items.

Control measures to prevent people being injured during the use and maintenance of plant must be provided and maintained as part of a safe system of work. Certain people have duties under the regulation to control workplace risks arising from the use of plant and moving plant.

Powered mobile plant (associated with excavation work) should be designed to include devices that protect the operator against rollover, falling objects or ejection, and warning devices for those at risk from moving plant.

Earthmoving machinery designed to have a mass of 700–100 000 kg should include a protective structure that complies with *AS 2294.1 – Earth-moving machinery – Protective structures – general.*

Plant control measures include:
- guarding to prevent contact with moving, or hot parts (e.g. nip, shear and pinch points, rotating shafts and exhaust systems)
- barricading or fencing to prevent access to hazardous areas or as fall protection
- means for safe access and egress
- implementing rollover protective structures (ROPS) and falling object protective structures (FOPS)
- using reversing sensors and cameras to cabin CCTV
- using eye protection
- installing reversing beepers and flashing hazard lights
- providing adequate lighting
- installing fire safety equipment, and
- providing ongoing maintenance, including underground servicing complexes.

4.4.2 Plant and vehicle movement procedures

Plant and vehicle movement is a potential hazard. A crush injury is the most common risk that can arise from activities, such as:
- transporting and installing fixed equipment (e.g. transformers)
- moving self-relocatable plant (e.g. road header, TBM, drill rig, rock bolter), and
- moving other vehicles in the tunnel (e.g. haul trucks, left-hand drive, service and delivery vehicles, personnel carriers, locomotives, rail cars and loaders).

Procedures for safe plant and vehicle movement should be developed based on a risk assessment, and should be updated as the conditions on the site change. Risk assessments should be carried out relevant to the issues involving moving plant, but due to the confined environment and restricted lighting and noise, the tunnelling environment places additional constraints on the available controls.

Control measures include:
- reducing vehicle movements by using conveyors to remove spoil, and coordinating deliveries to and from the work areas to reduce empty or near empty journeys (e.g. by back loading)
- scheduling activities to reduce traffic congestion
- using a traffic management system
- lining the tunnel floor, or maintaining it regularly

- having vehicle operators remain in the cabin during loading/unloading, providing there is no risk and they are not required to assist with the loading/unloading activities
- providing pedestrian shelters
- cleaning windows and lights, and
- providing high visibility, reflective clothing and cap lamps.

Note: Cap lamps are often used as a communication tool amongst tunnel workers.

4.4.3 Plant suitability and assessment

Designers of plant and equipment have a duty under the Act to ensure the plant is designed to be safe when used properly and should provide information about the way the plant must be used to ensure health and safety.

Plant selected for a tunnelling project should be chosen for its performance and suitability against a number of criteria, including:

- duty requirements (e.g. whether designed for use underground or in need of modification)
- compliance with regulations and relevant standards (e.g. electrical standards)
- physical dimensions and requirements (e.g. clearance available, ventilation, power and water)
- appropriate levels of emissions (e.g. exhaust, noise, vibration and heat)
- whether the plant is safe and easy to operate and maintain
- the plant's contribution to a safe working environment (e.g. ability to erect roof support immediately behind the excavated face, or ability to eliminate or minimise dust), and
- the skills and training required to operate and maintain the plant safely.

Manufacturers of plant have a duty under the Act to provide other people who have duties with all the available and necessary information about the plant to enable them to fulfil their duties. The information should include the:

- purpose for which the plant was designed
- testing or inspections to be carried out on the plant
- installation, commissioning, operation, maintenance, cleaning, transport, storage and dismantling the plant if necessary
- systems of work needed to use the plant safely
- knowledge, training or skills necessary for people undertaking testing and inspection of the plant, and
- emergency procedures.

Note: Equipment specifically designed for a project, including one-off items constructed by the tunnel builder, also requires a risk assessment and provision of the above information.

Where plant is used for purposes for which it was not designed (e.g. fitting an attachment, direct modification or a change in the way it is used), a competent person should conduct a risk assessment to determine if the changes have increased the risk to health and safety and whether there is a need for additional control measures to be implemented, and information provided.

4.4.4 Fuelling – surface and underground

Fuel used for diesel engines underground should not have a flash point below

61.5 °C and should contain less than 10 ppm sulphur[5]. Where practical, fuelling should be conducted on the surface. Engines should be switched off and there should be no naked flames, lights or smoking in the fuelling area.

Surface fuelling should only be conducted in designated fuelling bays that are:
- adequately ventilated
- a safe distance from traffic and roads
- built of non-flammable materials
- constructed with a sill or bund to prevent fuel escaping
- not used for vehicle repairs or servicing
- without any naked flame
- provided with suitable fire extinguishers, and
- provided with a hose and pump, with a self-closing nozzle and a shut off tap to prevent fuel leakage when unattended (gravity-method fuelling may also be considered).

For underground fuelling:
- transport and store fuel in strong containers that do not leak
- limit stored fuel to minimum quantities required for efficient operations
- use an oil-absorbent material to clean up spills (dispose of used material promptly).

For surface fuelling, the fuelling station should be:
- properly signposted
- surrounded by traffic barriers
- locked when not in use.

4.4.5 Personnel-riding vehicles

Personnel should be transported in vehicles that are designed for this purpose. These vehicles should have:
- seating for each person
- overhead protection and an enclosure to ensure passenger safety
- suitable access (e.g. doors and steps)
- ways for passengers to signal the driver, particularly if the driver is unable to see the passengers
- communication systems, and
- enough space for a stretcher and the ability to transport injured people.

If not self-propelled, the vehicle should be towed by a locomotive or prime mover, rather than pushed.

Personnel should not be transported with explosives, spoil or construction materials, except where it has been assessed that there is no risk to passengers.

4.4.6 Rolling stock – locomotives and rail cars

Diesel and electric locomotives and rail cars are commonly used to carry materials and people in long tunnels.

[5] Australian Diesel Fuel Standards under the *Fuel Quality Standards Act (2000)*. .

As well as the general plant issues, the risk management process for rolling stock should consider:

- maximum grade
- power, diesel or electric
- fail safe brakes with dead man control
- speed limiters, governors
- couplings
- signalling systems
- communication systems
- the rail track
- pedestrian access
- appropriate stock
- derailments, including prevention measures, systems and equipment
- tipping systems, and
- buffer stops.

4.4.7 Conveyors

Conveyors are used in tunnels to transport spoil from the face to muck cars, or directly to the spoil stockpile or disposal area on the surface. A number of conveyor types are available for use, and information on conveyor safety can be found in *AS 1755 – Conveyors – Safety requirements,* which sets out the minimum safety requirements for the design, installation, guarding, use, inspection and maintenance of conveyors and conveyor systems.

The risk management process should identify and eliminate (or control) the hazards and risks associated with conveyors. For tunnelling, the following control measures should be considered:

- isolating conveyors from normal work areas to prevent limbs or the body from becoming entangled (e.g. guarding)
- preventing people from riding on conveyors
- providing fire extinguishers
- preventing oversize material from entering the conveyor system
- reducing spillage from overloaded conveyors (e.g. regulate the conveyor's feed rate and belt speed)
- suppressing dust (e.g. water sprays at drop points, extraction ventilation at drop points, enclosed conveyors)
- implementing power isolation procedures to allow for maintenance, spillage clean-up, and cleaning the rollers, and
- implementing procedures after shutdown and maintenance.

4.4.8 Cranes, hoists and winches

Cranes and hoists (e.g. winches) are used as lifting plant for materials and people. As well as general plant issues, there are specific requirements for cranes and hoists, such as design standards, risk control measures, and registration requirements.

4.4.9 Specialist plant

Control measures to prevent people being injured during the use and maintenance of all plant, including specialist plant that is used in tunnel construction, must be provided and maintained as part of a safe system of work. All plant, even custom-designed plant, is subject to the same duties under the Act and regulation.

Specialist plant used in tunnel construction is categorised as moving plant (see 4.4.1).

4.4.9.1 Shotcrete rigs, jumbos, road headers, TBMs and electric tunnel muckers

Some of the significant issues regarding specialist plant like shotcrete rigs and road heads include:

- avoiding standing under unsupported ground unless protected by overhead protection
- having ventilation close to the face to remove dust
- locking-out the plant according to the manufacturer’s instructions (e.g. isolating the power, discharging accumulators), before accessing the face or carrying out maintenance, repairs or pick changes
- avoiding standing near plant that is likely to move, or near movable parts of the plant (e.g. gathering arms, tail conveyors, booms), when the operator’s vision is restricted
- avoiding falling objects (e.g. from the tunnel, conveyors or booms), and
- avoiding rotating drill steels that can catch clothing and hair.

4.4.9.2 Other purpose-built tunnelling equipment

Other purpose-built tunnelling equipment (e.g. formwork, liner-segment handling equipment, spoil-car tipping station), also fall under the definition of plant, and the designer and manufacturer have the same duties as manufacturers and designers of any other plant.

4.5 Other tunnelling risks

The underground work environment of tunnelling operations has a number of common risk areas including:

- limited space and access
- the use and maintenance of considerable heavy equipment, some electrically powered
- compressed air use
- projected particles from rock breaking, drilling or cutting
- manual tasks
- large scale materials handling
- uneven surfaces
- heights
- falling objects
- ground and process water
- reduced visibility
- high noise levels
- vibration, and
- the possibility of poor ground conditions, hazardous chemicals and air contamination.

4.5.1 Noise

High noise levels can be generated in tunnels because of the enclosed work environment, and plant and tunnelling activities.

The regulation requires a PCBU to ensure that appropriate control measures are implemented if a person is exposed to excessive noise levels above:
(a) an eight hour equivalent continuous A-weighted sound pressure level of 85dB(A), referenced to 20µPa, or
(b) a C-weighted peak sound pressure level of 140dB(C), referenced to 20µPa.

Further guidance on noise is available in the *Managing Noise and Preventing Hearing Loss at Work Code of Practice.*

As a general rule, if it is necessary to use a raised voice to communicate with a nearby person (i.e. one metre away), it is advisable to carry out an assessment.

In assessing noise levels, the PCBU should note that:
- hearing loss or damage is related to both the duration of exposure and loudness of the noise
- hearing loss is permanent
- engineering solutions to high noise levels are the most effective, and
- assessments should be carried out by competent persons[6].

Specific noise hazards and risks include:
- poor sound-insulated stationary equipment (e.g. compressors)
- high noise activity (e.g. rock drilling, air tools)
- high noise mobile equipment (e.g. loaders, road headers and shotcrete machines).

Control measures for noise include:
- isolating the noise using engineering solutions, such as:
  - constructing sound-deadening structures around static plant
  - fitting sound-attenuating silencers to fans
  - fitting and maintaining mufflers to exhausts (e.g. critical residential type mufflers)
  - applying soundproofing material to walls and around equipment
  - selecting low noise and vibration equipment
- reducing effects of high noise activity by:
  - fitting sound absorbing material (e.g. workshop walls)
  - limiting people in high noise areas (e.g. at the face during drilling)
  - initiating blasts from a distance (e.g. from the surface)
  - enforcing personal hearing protection use
  - limiting exposure times
  - providing training in use and maintenance of personal hearing protectors[7]
  - selecting suitable personal hearing protectors
  - including noise issues regularly in tool box safety meetings, and
- reducing effects of high noise mobile equipment by:
  - selecting plant with lower noise output and/or its own acoustic enclosure
  - increasing efficiency of silencers
  - fitting additional mufflers to exhausts.

If a worker is frequently required to use personal protective equipment to protect the worker from the risk of hearing loss associated with noise that exceeds the exposure standard for

[6] Refer to *AS/NZS 1269* Part 1 Appendix A for Competency requirements of people undertaking noise assessments.
[7] This may, as a minimum, be done in accordance with *AS/NZS 1269 Part 3*.

noise, the duty holder who provides the personal protective equipment as a control measure must provide audiometric testing for the worker:

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

audiometric testing means the testing and measurement of the hearing threshold levels of each ear of a person by means of pure tone air conduction threshold tests.

Workers should have baseline screening audiograms (hearing test) before commencing work, and repeated at a minimum two-yearly interval.

Workers who are exposed to noise and ototoxic[8] agents (e.g. fuel vapours, solvents or gases, such as carbon monoxide in excess of 50 per cent of the relevant exposure standard) should also be audiometrically screened and their noise exposure minimised.

4.5.2 Hazardous chemicals

When hazardous chemicals are introduced into a tunnel (or into an enclosed space), care must be taken to reduce the chance of spillage or loss of containment which could create a hazard. Some of these hazardous chemicals have established workplace exposure standards that must be observed.

The regulation sets out the requirements for managing risks arising from the use of hazardous chemicals.

Only sufficient quantities of hazardous chemicals for use during one day or shift should be held below ground. A risk assessment must be conducted, before a new substance is introduced to the underground workplace, to determine if there is a potential for the substance to cause hazardous contamination of the air or ground during normal use, storage and if containment is lost.

The safety data sheet (SDS) supplied by the manufacturers or importers will provide information on the hazards associated with the substance, including how to deal with spillage, leaks and fires. Written procedures for safe use and handling, including emergency procedures, should be prepared for all substances posing a significant risk. Training should be given to all people using these substances.

Where hazardous chemicals are used, a PCBU must:

- prevent exposure beyond the standard exposure limits
- train workers in the safe use of the substance and ensure they have access to the manufacturer's/importer's SDS
- ensure that any necessary PPE is available and used
- ensure that all containers are labelled, especially when a hazardous chemical is decanted
- ensure that all containers are cleaned when empty
- keep a register of hazardous chemicals used and a record of training provided, and
- arrange for health monitoring (e.g. baseline and two yearly lung function testing), for workers who could be exposed to crystalline silica.

[8] Ototoxic = ear; ear damaging agents.

4.5.2.1 Health monitoring for hazardous chemicals

In tunnelling environments, hazardous chemicals for which health monitoring may be required by regulation is limited mostly to crystalline silica. The requirements for health monitoring are provided in Schedule 14 of the Work Health and Safety Regulation 2011.

Generally, chest x-rays are not required until 10 years after the first exposure, assuming that the worker has not had prior exposure to silica in other jobs. However, the need for health monitoring is determined by the level of risk resulting from the exposure to respirable crystalline silica. Health monitoring would be indicated if air monitoring results show workers have been and are being consistently exposed to elevated levels of respirable crystalline silica Health monitoring is undertaken by a registered medical practitioner with experience in health monitoring.

4.5.3 Visibility and lighting

The PCBU should ensure that lighting is provided which:
(a) is adequate to allow workers to work safely, and
(b) does not create excessive glare, and/or
(c) is adequate to allow people who are not workers to move safely within the workplace, and
(d) facilitates safe access and egress from the workplace, including emergency exits.

Further guidance on lighting is available in the *Managing the Work Environment and Facilities Code of Practice.*

Poor visibility can result in:

- collisions
- people being struck or run over by plant
- inability to assess ground and plant conditions, and other potential hazards
- slips, trips, falls and other injuries
- fatigue.

Control measures to provide adequate lighting include:

- hard-wired lighting at transformer installations, workshops or service bays, fuelling points, pump stations or sumps, stores areas, crib rooms, loading points, unloading points, shaft and tunnel intersections, plant rooms, and in the transition zone some distance into the tunnel
- additional lighting at the face area (e.g. lighting on the platform of mobile equipment)
- adequate lighting for detailed work, hazardous processes, and where machinery is being operated, and
- emergency egress lighting.

If there is any credible circumstance in which the lighting, and in particular the emergency lighting, may fail then the duty holder should ensure that every person entering the tunnel is issued with a cap lamp. Where cap lamps are provided:

- one cap lamp charged and maintained for each underground person
- adequate lamps to allow each lamp to be fully charged and provide at least 12 hours light each shift
- spare cap lamps for other people who may be underground on any given day;
- cap lights do not increase igniting risks
- cap lights can produce sufficient light to guide the user in the event of a underground fire.

4.5.4 Compressed air

Compressed air systems include air compressors, receivers (pressure vessels) that may be stand-alone or contained within the compressor unit, water traps, and reticulation, such as valves and hoses supplying compressed air powered tools and equipment. These systems may create hazards and risks during installation and use.

The risks of compressed air include:

- a sudden release of pressure due to a failure with pressure vessels or pipes, flexible hoses and tools
- incorrect installation of pipes, inadequate pressure rating, stressed joints
- incorrect work methods (e.g. pressure not bled before working on reticulation, checks not made before pressurisation, uncoupling hoses under pressure, not fitting clips or chains)
- unsafe acts (e.g. cleaning with compressed air without appropriate PPE)
- absence of or inappropriate PPE
- breakdown products of oils in compressed breathing air including carbon monoxide,, and
- contamination of the atmosphere by oils or exhaust in compressed air.

Control measures for eliminating the risk of compressed air could include:

- ensuring that all compressed airlines have appropriate colour coding or signage
- installing isolation valves 200 m apart and at intersections
- supporting pipes at each end before a joiner, and to the wall or roof
- ensuring traffic has adequate clearance around plant
- using appropriate equipment (e.g. correct pressure-rated equipment, such as hoses, valves and pipe work, and compressors that supply oil free air)
- maintaining equipment appropriately (e.g. maintain lines, repair leaks promptly, place receivers in protected positions, clip hoses and chain joints for hoses more than 50 mm in diameter)
- storing equipment safely (e.g. keep compressor outlets away from diesel exhausts)
- conducting periodic checks (e.g. check pressure gauges on receivers, check valves before turning on air, clear water traps and drains daily, bleed all pressure from systems before disconnecting, re-pressurise slowly, check pressure fittings for tension or other loads, use compressed air appropriately), and
- using appropriate PPE (e.g. wear safety glasses and ear plugs when blowing out holes).

4.5.5 Electrical safety

The Act sets out the relationship with the *Electrical Safety Act 2002,* which requires duty holders to ensure that:

Electrical installations at workplaces

- All electrical installations at a workplace are inspected and tested, after they are installed and prior to their energising for normal use, by a competent person to ensure they are safe for use.
- All electrical installations at a workplace are maintained by a competent person to ensure they remain safe for use.

Electrical articles used in construction work

- All electrical articles that are used in construction work are regularly inspected, tested and maintained by a competent person to ensure they are safe for use if the articles are supplied with electricity through an electrical outlet socket.

Electrical articles that may be affected by adverse environment

- All electrical articles that are supplied with electricity through an electrical outlet socket that are at a workplace where the safe operation of the electrical article could be affected by an adverse operating environment should be regularly inspected, tested and maintained by a competent person to ensure they are safe for use.

Electrical installations and articles found to be unsafe

- All electrical installations and electrical articles at a workplace that are found to be unsafe are disconnected from the electricity supply and are repaired, replaced or permanently removed from use.
- Plant is not used in conditions likely to give rise to electrical hazards.
- Appropriate work systems are provided to prevent inadvertent energising of plant connected to the electricity supply.
- If excavation or tunnelling work is to be carried out at a workplace, all available information concerning the position of underground electrical cables must be obtained and disseminated to people at the workplace.
- People at work, their plant, tools or other equipment and any materials used in or arising from the work do not come into close proximity with overhead electrical powerlines, except if the work is done in accordance with a written risk assessment and a safe system of work and the requirements of the relevant electricity supply authority.
- Any electrical cord extension sets, flexible cables or fittings:
  - are located where they are not likely to be damaged, including damage by liquids or are protected against any damage
  - are not laid across passageways or access ways unless they are suitably protected
  - have adequate hazard warning signs, and (if necessary) restrict access, at or near any area in which there is a risk of exposure of people to hazards arising from electricity.

Electrical hostile operating environment

A hostile electrical environment means an operating environment at a workplace where an electrical article is in its normal use subjected to operating conditions that are likely to result in damage to the article. Such environment includes an operating environment that may:

- cause mechanical damage to the article; or
- expose the article to moisture, heat, vibration, corrosive substances or dust that is likely to result in damage to the article.

This section of the code on electrical safety should be read in conjunction with the following standards and installation rules:

- *AS/NZS 3000 – Electrical installations* (known as the Australian/New Zealand Wiring Rules), which is mandatory under the *Electrical Safety Act 2002*.
- *AS/NZS 3012 – Electrical installations – Construction and demolition-sites*.

4.5.5.1 Installation, inspection, testing and record keeping

All electrical installations associated with tunnel construction must be inspected and tested by a competent person to ensure they are safe, after installation and before energising for normal use.

All electrical articles used in tunnel construction work must be regularly inspected, tested and maintained by a competent person to ensure they are safe for use, if the articles are supplied with electricity through an electrical outlet socket.

All electrical installations and electrical articles associated with tunnel construction that are found to be unsafe must be disconnected from the electricity supply and repaired, replaced or permanently removed.

4.5.5.2 Electric cables – reeling and trailing

There should be a cable management system in place specifying minimum installation requirements to ensure that reeling or trailing cables are protected from damage. Trailing cables must only be handled during normal operation using appropriate PPE, such as hooks, tongs, slings, or other PPE and equipment designed for the purpose.

4.5.5.3 Cables – construction wiring

Construction wiring and switchboards should be supported and positioned at a height above the tunnel floor to prevent damage from passing vehicles, mobile equipment and falling rocks.

Single and three-phase final sub-circuits must be protected by a residual current device (RCD) with a rated tripping current not exceeding 30 mA, which operates in all live (active and neutral) conductors. This includes:

- construction lighting
- socket outlets supplying hand held or portable equipment
- relocatable structures.

Light fittings should be fitted with a cover to protect against moisture and dust.

4.5.5.4 Portable generators

Portable generators should not be used or placed in tunnels unless they are diesel-powered and fitted with exhaust scrubbers. Portable generators should comply with the principles of *AS 2790 – Electricity generating sets – Transportable (up to 25 kW).* Depending on the type of generator, they should be connected to the wiring and equipment in accordance with *AS/NZS 3012- Electrical installations – Construction and demolition-site*, and *AS/NZS 3010 – Electrical installations – Generating sets.*

4.5.5.5 High voltage installations

A competent electrical engineer should design the high voltage reticulation system for tunnel construction. They should also certify that the high voltage earthing systems have been tested and that all the electrical protection will operate properly should an earth fault occur.

The PCBU must ensure that people working on the high voltage system hold a current certificate for high voltage work, or are directly supervised by a person qualified to do the work.

An access permit system must be in place to monitor all people who access high voltage installations.

High voltage detectors

A detector must be available to prove that high voltage conductors and equipment have been de-energised. The detector should be tested using a source from the appropriate system voltage (another in-service conductor), or fitted with a checking device, to ensure that it works correctly. Detectors should be tested annually.

Isolation of high voltage
Isolation or reconnection of high voltage supply must only be carried out by competent, authorised people.

Before any high voltage work commences, correct isolation procedures should be in place, such as:

- identifying all the equipment to be isolated
- determining the correct point of isolation
- carrying out the isolation
- testing the effectiveness of the isolation, and
- placing safety lock/tag(s) on the isolating device(s).

Re-energising
There should be set procedures for restoring the power in the high voltage system, to ensure everyone is clear before re-energising. Before power is restored after a fault trip, an investigation into the cause of the trip should be undertaken by a competent person.

Signs
Signs indicating DANGER – HIGH VOLTAGE should be in suitable positions along the entire length of the high voltage cable. Signs must be placed on the outside of the substation enclosure, and at each entry point. Appropriate signs must also be placed on all high voltage plant and equipment. An AUTHORISED PERSONS ONLY sign must be placed on all doorways and panels of the substation. High voltage switchgear and associated equipment should be clearly labelled to indicate the portion of the electrical installation that it controls.

4.5.6 Welding (and oxy-cutting)

Particular risk control measures for welding, includes exposure to atmospheric contaminants and other hazards, and ultraviolet radiation.

A PCBU, who could be a PCBU and the principal contractor, has duties under the Act to ensure that:

- risks associated with people exposed to atmospheric contaminants arising from welding, including fumes, gases and vapours emitted from materials used during the welding process and from materials being welded, are controlled by using one or more of the following measures (in descending order of priority):
  - substituting a less hazardous process, material or procedure; or
  - using appropriate ventilation.
- people directly involved in welding wear appropriate personal protective equipment
- adequate hazard warning signs are provided at or near any area in which there is a risk of other people being exposed to welding hazards
- risks associated with people exposed to harmful levels of ultraviolet radiation at or near the welding site are controlled by using the following measures (in descending order of priority):
  - appropriate screens are provided and used to protect workers from ultraviolet radiation

- people working in an area where there is a risk of exposure to ultraviolet radiation, wear appropriate personal protective equipment, and
- people who are not welding are prevented from entering an area where there is a risk of exposure to ultraviolet radiation, and that adequate hazard warning signs are provided.

Additional control measures that should be considered include:

- fitting flash back arrestors to gas-based welding equipment
- storing gas-based welding cylinders upright and in well-ventilated areas
- limiting below ground storage, to prevent the build-up of explosive atmospheres
- providing additional extraction ventilation when welding
- preventing the ignition of substances that could cause a fire, and
- fitting voltage reduction devices to electric welders.

4.5.7 Confined spaces

Further guidance on confined spaces is available in the *Confined Spaces Code of Practice*.

4.5.8 Manual tasks

Manual tasks are any activity requiring the use of force exerted by a person to grasp, manipulate, strike, throw, carry, move (lift, lower, push, pull), hold or restrain an object, load or body part. Manual tasks are part of nearly all work performed during the tunnelling process (e.g. operating heavy machinery, installing reinforcement mesh, using hand tools or maintaining conveyor belts).

Manual tasks are one of the main hazards that cause musculoskeletal disorders, such as:

- muscle strains and sprains
- damage to discs and ligaments in the back, and
- injuries to nerves, ligaments and tendons in other parts of the body, such as shoulders, knees and other joints.

Further guidance on manual tasks is available in the *Hazardous Manual Tasks Code of Practice.*

The major risk factors (direct stressors) for manual tasks include:

- the level of muscular force exerted
- working postures
- repetition of actions
- the vibration absorbed from equipment, and
- the duration of time these conditions are sustained.

A direct stressor must exist for a risk of injury from manual tasks to be present.

The direct stressors are the result of:

- the work area layout
- use of tools
- nature of loads
- load handling.

Work organisation and individual factors also have an impact on the risk factors. If these factors are redesigned, the impact of the direct stressors can be reduced.

Control measures for manual tasks fall into two major categories – design and administrative controls.

Design controls make changes to the work area, tools or equipment or the way a job is done, and/or provide mechanical aids to reduce the effort required to do the job. Design controls are preferred, as they are permanent and can eliminate or minimise exposure to risk factors.

Administrative controls make changes to work practices, policies and procedures to reduce exposure to the risk of a musculoskeletal injury. Administrative controls are less preferred as they:

- only reduce exposure to the risk factors
- rely on the worker to follow the procedures
- require ongoing supervision to ensure they are implemented
- may be forgotten under stressful conditions (e.g. when trying to meet deadlines).

Manual tasks should be considered at the planning and design stage of the tunnelling project to eliminate or minimise the manual tasks risks to workers. Work methods should be considered, including the materials and equipment to be used and their implications for manual tasks risks, for example:

- Can mechanical aids be used to move heavy materials?
- Can workers easily operate the necessary tools and equipment?
- Can workers perform tasks without assuming awkward postures or exerting excessive force?

The manual tasks risks for the end users (e.g. workers and all other people affected), should also be considered in the design stage (e.g. the manual tasks requirements to repair and maintain the tunnel).

4.5.8.1 Examples of design controls

Job design and redesign

- purchase materials in bulk or in smaller sizes which can be easily handled, and equipment and tools that can be easily operated and maintained without the need to assume awkward postures or exert excessive force
- ensure work surfaces, such as conveyor belts or work benches, are at a height which allows workers to adopt an upright and forward facing posture when using them
- ensure adequate lighting so that workers can easily see the tasks being performed, therefore minimising awkward postures
- use automated or mechanised systems to eliminate handling wherever possible (e.g. use remote control shotcrete machines)
- use bulk handling or palletised systems or place items in pots or cradles so that loads can be moved using mechanical aids
- place materials, store supplies and equipment close to the point of use to minimise double handling and the distance over which loads are moved
- ensure access ways are clear so that materials and equipment can be easily accessed, and
- use ergonomically-designed power tools instead of manually-operated hand tools.

Mechanical aids

- Use mechanical aids, such as cranes, hoists, or forklifts to move equipment and materials wherever possible (e.g. when moving drums of hydraulic oil, electric cable or pipes). Team lifting is not a preferred method for load handling and should only be used as a last resort when mechanical aids cannot be used or the work cannot be redesigned.
- Use elevating work platforms to minimise overhead reaching, such as when installing rock bolts.

4.5.8.2 Examples of administrative controls

Policies and procedures

- develop safe work procedures for high risk tasks, such as replacement of cutters, or repairs to conveyor belts, or emergency situations, such as breakdowns or accidental damage (e.g. removal of damaged concrete panels), and
- include manual tasks risk assessments in purchasing policies and procedures to ensure the selection and use of safe designs.

Work organisation

- incorporate rest breaks or task variety into the job where the extended exposure to the risk cannot be eliminated or minimised, and
- ensure there are adequate workers to meet deadlines.

Task-specific training

- provide workers with education and training in manual tasks risk assessments, safe work practices, including the correct use of mechanical devices, tools and equipment, work procedures and handling methods (e.g. team lifting).

Preventative maintenance program

- Clean and maintain tools and equipment regularly. Tools and equipment, which are not properly maintained, may require increased force to use them.

Personal protective equipment (PPE)

- PPE and clothing can increase the potential for injury if it is lacking or unsuitable for the work being done. For example, incorrectly sized gloves interfere with a worker’s gripping ability and manual dexterity, which contributes to increased muscular effort and fatigue. If PPE is worn, it is important that the appropriate type is chosen based on the work requirements and different sizes are provided so that the worker can select the right size.

4.5.9 Falls from heights

Further guidance on fall prevention is available in the *How to Prevent Falls at Workplaces Code of Practice.*

A PCBU and the principal contractor are required to provide safe means of movement between different levels. Tunnels under construction have an increased risk of falls due to the wet, slippery or uneven ground, inadequate lighting, or inappropriate PPE.

Areas where fall protection could be required include:

- shafts, pits, trenches and sumps
- cuttings and benches
- elevated structures (e.g. ventilation ducts, working platforms, service platforms, ladders, stairs, formwork, lifts and scaffolding)
- bins, walls, roofs, portal walls and batters, and
- plant, bins, tanks and loader buckets.

In addition to the control measures specified in the regulation, the following control measures may be appropriate:
- improved lighting
- stairways instead of ladders
- signposting hazards, and
- housekeeping, such as removing trip hazards, grading roadways and rectifying slippery areas.

4.5.10 Falling objects

> Under the regulation, a PCBU and the principal contractors must ensure that risks associated with falling objects are controlled.

The following are highlighted for the particular risk of falling objects, from or into:
- shafts, including working stages or platforms within them
- pits, trenches, sumps and benches
- equipment, bins, tanks, kibbles, spoil stackers, lifts and plant
- building of roofs or walls of the tunnel, cuttings, portal walls or batters
- rock and other material falling from passing trucks or during spoil loading and unloading, and
- elevated structures, such as conveyors, hoisting facilities, bins, tipping mechanisms for spoil, working platforms, formwork, ladders and scaffolding.

Control measures to reduce the risk of falling objects include:
- prompt installation of ground support
- modifying design (e.g. kick (toe) boards, chutes, splash plates)
- prohibiting work above other people
- installing screens, overhead protection, protected walkways, lock-out danger areas, and
- housekeeping of floors and access ways, cleaning up spillage, using lanyards or thongs on tools.

4.5.11 Vibration

The operation of certain tools and plant used in tunnels can expose people to high levels of harmful vibration. The types of hand held plant that can cause vibration are rock drills, jack picks, concrete vibrators and air tools. Mobile plant can also cause high whole body vibration levels.

Contractors should check ‘tool in use’ vibration emission data from manufacturers or suppliers of tools that cause arm vibration at the tendering stage, to identify and select vibration reduced hand tools suitable for the job, but with low vibration levels.

Contractors should prepare risk assessments based on gang size and work shift patterns, including exposure to vibration risk, likely to occur during the work. Where hand arm vibration exposure exceeds $2.9 m/s^2$, the exposed workers must have regular health monitoring as determined by an occupational physician.[9]

Control measures that can reduce vibration include:

- using tools and equipment suitable for the job, with the lowest vibration levels
- replacing hand-held machines with remote controlled systems (e.g. rock-drilling jumbos or slide-mounted drills)
- fixing 'out-of-balance' items
- servicing plant regularly to the manufacturer's specifications to reduce vibration
- using vibration-absorbing handles, or rubber-type vibration insulating devices between the tool and the hands
- providing foot-pusher plates for sinking drills
- providing suspended or vibration-absorbing seating in plant
- providing suspension dampened and padded seating in personnel-riding vehicles, and
- minimising exposures through administrative controls, such as job sharing, to ensure vibration exposure is managed, controlled and maintained below $2.9 m/s^2$ over the entire shift.

Control measures that can reduce the effects of vibration include:

- providing workers with training and instruction before the work begins about the:
  - need to keep vibration exposure down to avoid hand arm vibration syndrome
  - need to keep tools sharp
  - tool maintenance regime
  - handling of tools
  - need for job sharing
  - need to keep hands warm and dry
  - need to stop or reduce smoking.
- including vibration issues regularly in tool box safety meetings
- issuing suitable clothing and gloves to assist blood circulation by keeping the worker's hands warm
- reviewing and adapting work procedures involving hand arm vibration immediately to ensure exposures are kept below $5.0 m/s^2$, and
- ensuring female drivers who are pregnant, or have recently given birth, and are required to drive vehicles or mobile plant used with tunnelling activities, are not exposed to work involving risks arising from unpleasant vibration of the entire body, particularly at low frequencies, microtraumas, shaking, shocks or where jolts or blows are delivered to the lower body exceeding an eight hour daily exposure of $0.5 m/s^2$.[10]

4.5.12 Eye injury

Projected objects or hazardous chemicals could cause an eye injury.
Some of the hazards may be:

- physical, such as rock, metal shards, glass, mud and dust
- chemical, such as acids, fuel, cement powders, oil and ammonium nitrate

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[9] More information can be accessed in *AS 2763,* Appendix B for Health monitoring requirements.

[10] In the absence of Australian exposure standards for whole body vibration, the limits should be based on the European Directive: *Directive 2002/44/EC.*

- laser beams.

Risks can include:
- high pressure water
- acidic ground and polluted water
- electromagnetic fields or radiation from welding.

Risk factors should be considered when:
- repairing plant and equipment
- installing support
- welding
- working on pumps or water lines
- turning on air and water
- blowing out hoses, and
- hammering steel, dropping objects, or handling substances.

Risks of eye injury can be eliminated or controlled by:
- using alternative methods, such as tunnel machine methods (not drill and blast), or automatic drilling machines
- draining pressure from air lines before work
- covering substances when handling
- avoiding pouring or improvising when handling hazardous chemicals
- using fitting guards and screens
- using engineering methods
- providing appropriate training, instruction and information, and
- using PPE during hazardous activities, and eye protection at all times regardless of the activities.

4.5.13 Radiation

4.5.13.1 Lasers

Laser radiation must be controlled by limiting access to laser beams. Uncontrolled exposure to laser beams can cause severe eye damage, including cataracts. Engineering methods, administrative controls and personal protective equipment must be considered to supplement other control measures.
To determine the effectiveness of a safety control measure, consider the following:
- the conditions under which the laser is used
- the level of safety training of individuals using the lasers
- results of medical surveillance
- service and maintenance procedures, and
- other environmental factors.

The use of laser systems should be evaluated by those who are trained in this area and are familiar with the requirements for laser safety. Requirements for laser safety include:
- laser certification in accordance with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) standards
- assigning laser safety officers
- proper classification of lasers
- warning signs and labels

- medical surveillance
- administrative controls
- engineering controls, and
- personal protective equipment.

More detailed information on laser classification and safety can be found in the *AS/NZS 2211 – Safety of Laser Products series.*

4.5.13.2 Ionising radiation

When geologic investigations are supported by gamma ray and gamma ray density measurements (e.g. to establish a model of the geology at tunnel level), risk assessments must be carried out by a competent person. Health and safety procedures are to be developed for the use of gamma ray equipment. A radiation and protection plan should be produced before any ionising equipment is brought to the tunnel site and used.

The duty holder(s) should ensure that the radiation safety and protection plan being used has been approved by the Chief Executive of Queensland Health.

More information on this and other radiation issues may be found in the *Radiation Safety Act 1999* and *Radiation Safety Regulation 2010*.

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Appendix 1: Example hazard identification chart

The table below shows a sample of potential hazards that present dangers of personal injuries in tunnels, based on risk analyses prepared by domestic contractors. It is important that all workers working underground recognise the special risk factors.
Also everybody, depending on the behaviour of their colleagues, should be aware of this, including the management in charge of the tunnel project.

Example of a hazard identification chart

Item	Explosion	Fire	Rock burst or fly rock	Objects into eye	Gas dust	Injury from electricity	Fall injuries	Traffic	Pinch injury
Drilling									
Blasting									
Loading									
Charging holes									
Scaling from pile									
Machine scaling									
Storing explosives									
Storing gas									
Ventilation work									
Grouting of bolts									
Electrical work									
Hot work									

Appendix 2: Useful reference materials

Standard	Ref. number	Title
Acoustics – hearing protectors	*AS 1270*	Acoustics – Hearing protectors
Air conditioning units and cooling towers	*AS/NZS 3666* (set)	Air-handling and water systems of buildings – microbial control
Cranes, hoists and winches	*AS 1418* (set)	Cranes, hoists and winches set
	AS 2550 (set)	Cranes- Safe use set
	ISO 2374	Lifting appliances - Range of maximum capacities for basic models
Clothing - protective	*AS/NZS ISO 6529*	Protective clothing – Protection against chemicals – Determination of resistance of protective clothing materials to permeation by liquids and gasses
	AS/NZS 4503.2	Protective clothing – Protection against liquid chemicals – Test method: Determination of resistance to penetration by a jet of liquid (Jet Test)
	AS/NZS 4503.3	Protective clothing – Protection against liquid chemicals – Test method: Determination of resistance to penetration by spray (Spray Test)
Clothing – high visibility	*AS/NZS 4602.1*	High visibility safety garments – Garments for high risk applications
Confined space	*AS 2865*	Confined spaces
Conveyors	*AS 1755*	Conveyors - Safety requirements
Diesel engines	*AS 3584 (set)*	Diesel engine systems for underground coal mines set
Earthmoving machinery	*AS 2294.1*	Earth-moving machinery - protective structures - general
	AS 2958.1	Earth-moving machinery – Safety – Wheeled machines – Brakes
	AS 2958.3	Earth-moving machinery – Safety – Roller Compactors – Brake systems
Electrical installations	*AS/NZS 3000*	Electrical installations (Australian/New Zealand Wiring Rules)
	AS/NZS 3012	Electrical installations – Construction and demolition sites
	AS/NZS 3010	Electrical installations – Generating sets
Electricity generating sets	*AS 2790*	Electricity generating sets – Transportable (up to 25 kW)
Emergencies and planning	*AS 3745*	Planning for Emergencies in Facilities
	AS 1319	Safety signs for the occupational environment
	AS 2985	Workplace atmospheres – Method for sampling and gravimetric determination of respirable dust
Explosives	*AS 2187 series*	Explosives – Storage, transport and use series
Explosive-powered tools	*AS/NZS 1873 series*	Powder-actuated (PA) hand held fastening tools series
Eye protection	*AS/NZS 1337 Series*	Eye and face protectors series
Eye protection	*AS/NZS 1336*	Recommended practices for occupational eye protection
Fall-arrest	*AS/NZS 1891.4*	Industrial fall-arrest systems and devices – Selection, use and maintenance
Gas cylinders	*AS 2030 Series*	Gas cylinders series
	AS 2337 Series	Gas cylinder test stations series
	AS 3509	LP (liquefied petroleum) gas fuel vessels for automotive use
Industrial (forklift) trucks	*AS 2359 Series*	Powered industrial trucks series
Industrial rope access systems	*AS4488.1*	Industrial rope access systems – Specifications
	AS4488.2	Industrial rope access systems – Selection, use and maintenance
	BS EN 1263-1	Safety nets – Safety requirements, test methods
	BS EN 363	Personal fall protection equipment – Personal fall protection systems
	BS EN 365	Personal protective equipment against falls from a height – General requirements for instructions for use, maintenance, period examination, repair, marking and packaging
Lasers	*AS 2211 Series*	Safety of laser products series
	AS 2397	Safe use of lasers in the building and construction industry
Lifts	*AS 1735 Series*	Lifts, escalators and moving walkways series
Machinery	*AS 4024 Series*	Safeguarding of machinery series
	AS 1657	Fixed platforms, walkways, stairways and ladders – Design, construction and installation
	AS 1788.1	Abrasive wheels – Design, construction and safeguarding
	AS 1788.2	Abrasive wheels – Selection, care and use
	AS 1893	Code of practice for the guarding and safe use of metal and paper cutting guillotines
	AS 2661	Vapour degreasing plant - Design, installation and operation - Safety requirements

Standard	Ref. number	Title
	AS 2939	Industrial robot systems - Safe design and usage
	AS 3947.3; AS 3947.3 Supp 1	Low-voltage Switchgear and Control Gear – Switches, disconnectors, switch-disconnectors, and fuse-combination units
	AS 3947.4.3; AS 3947.5.3; AS 3947.5.5; AS 3947.5.6; AS 3947.6.1	Low-voltage Switchgear and Control Gear [specific information on different low-voltage switch-gear and control gear]
	AS 61508 Series	Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems series
	BS EN 61496-1	Safety of Machinery – Electro-sensitive protective equipment – General requirements and tests
	AS 2294.1	Earthmoving machinery – Protective structures – general
	AS 1755	Conveyors – Safety requirements
Occupational noise management	*AS/NZS 1269.3*	Occupational noise management – Hearing protector program
Pressure equipment	*AS/NZS 1200*	Pressure equipment
	AS 2593	Boilers – Safety management and supervision systems
	AS 2971	Serially produced pressure vessels
	AS/NZS 3788	Pressure equipment - In service inspection
	AS 3873	Pressure equipment - Operation and maintenance
	AS 3920	Assurance of product quality – Pressure equipment manufacture
	ISO/11439	High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles
Helmets	*AS/NZS 1800*	Occupational protective helmets – Selection, care and use
Helmets	*AS/NZS 1801*	Occupational protective helmets
Gloves	*AS/NZS 2161 (set)*	Occupational protective gloves set
Gloves – insulating	*AS 2225*	Insulating gloves for electrical purposes
Pressure piping	*AS 4041*	Pressure piping
Respiratory protective devices	*AS/NZS 1715*	Selection, use and maintenance of respiratory protective equipment.
	AS/NZS 1716	Respiratory protective devices
	AS 4774.1	Work in compressed air and hyperbaric facilities – Part 1: Work in tunnels, shafts and caissons.
Lighting	*AS/NZS 1680.0*	Interior lighting – Safe movement
	AS/NZS 2293.1	Emergency escape lighting and exit signs for buildings – System design, installation and operation.

Appendix 3: Dictionary

Acceptable engineering principles means principles, such as mathematical or scientific procedures outlined in an engineering reference manual.

Anchorage point means a device or thing by which a lanyard, static line or other line may be attached to a building or other structure, and includes the part of the building or structure to which the device or thing is attached.
Examples:

- a stainless steel eyebolt, set in a concrete floor, to which a lanyard may be attached;
- a sling around a steel I beam, with padding under the sling, joined by a shackle or other joining device to which a lanyard may be attached; and
- a plate for a travel restraint system fixed by screws to a roof component to which a lanyard may be attached.

Appropriate information means information which states the use for which the thing has been designed and tested and the conditions (if any) that must be followed if the thing is to be used safely and without risk to health and safety.

Barricade means a self-supporting fence, or a self-supporting series of continuous plastic, concrete or other solid barriers, usually temporary, erected or placed to restrict the entry of persons to a workplace.
Examples of fences:

- steel pickets joined by chain wire of appropriate height to restrict entry;
- steel pickets joined by rows of wire at appropriate heights to restrict entry; and
- steel pickets joined by taut plastic webbing commonly known as para-webbing.

Caisson means a structure that provides an underground passageway or a passageway through water.

Cofferdam means a temporary wall erected to exclude water from an area normally under water.

Common plant means plant provided by the principal contractor for use by any person at the workplace for a purpose other than discharging the principal contractor's workplace health and safety duties.

Competent person means a person who has acquired through training, qualification, or experience, or a combination of these, the knowledge and skill enabling that person to perform the task required (e.g. performing an inspection or other task for a risk management control measure). A competent person has acquired knowledge, including knowledge of:
(a) relevant Australian Standards; and
(b) relevant codes of practice; and
(c) other relevant legislation; or
(d) for work in relation to a trench; or
(e) for inspecting a mobile crane or tower crane.

Dogger means a person who:
(a) uses techniques, including the selection or inspection of lifting gear, to safely sling a load; or
(b) directs a crane or hoist operator in the movement of a load when the load is out of the operator's view.

Edge protection means a barrier to prevent a person falling erected along the edge of:

(a) a building or other structure; or
(b) an opening in a surface of a building or other structure; or
(c) a fall-arresting platform; or
(d) the surface from which work is to be done.

Erector means a person who erects, dismantles or alters the structure of plant in a workplace.

Fails safe means that when partial or total failure of plant occurs, the plant fails in a manner which leaves the plant in a safe condition and which does not introduce any additional condition which is unsafe.

Fittings are things that are fixed inside a building but can be removed.

Fixture means a piece of furniture or equipment which is fixed inside a building and which is left in place when the building changes hands.

Gantry means a structure that has:
(a) an overhead platform; and
(b) a hoarding, at least 1800 mm high that is fully sheeted with timber, plywood, metal or sturdy synthetic sheets, running along its length.

Geo-technical engineer means an engineer who holds an engineering qualification relevant to geo-technology.

Gunite refers to the dry-mix process, in which the dry cementitious mixture is blown through a hose to the nozzle, where the water is injected immediately prior to application. See also shotcrete.

Hazard means the potential to cause injury or illness.

Hazardous — potentially dangerous to people and or the environment.

Hiree of plant is a person or entity who hires plant from the hirer or plant hire company. The hiree should ensure the plant is used as it is intended to be used.

Hirers of plant are entities (plant hire companies) engaged in leasing, renting or hiring industrial machinery, plant or equipment from stocks physically held for that purpose, for set periods and without operators. These entities are suppliers for the purposes of the Act.

Hoarding means a self-supporting structure, fully sheeted with timber, plywood, metal or sturdy synthetic sheets, or fully covered by chain wire or sturdy mesh, that is designed:
(a) to prevent persons other than PCBUs or workers from entering a place where construction work is being performed; and
(b) to provide protection to those persons against objects approaching them from the side.

Importer means a person who imports plant for use in a workplace or plant intended to be used in a workplace.

Industrial robot means a multifunctional manipulator and its controllers, capable of handling materials, parts, tools, or specialised devices, through variable programmed motions for the performance of a variety of tasks.

Installer means a person who installs plant in a workplace.

Light work means work that is light having regard to the following:
(a) the amount of physical exertion involved;
(b) the physical capacity of the person doing the work;
(c) the range of movement involved; and
(d) the weight or bulk of materials or equipment involved.

Examples of light work:

- painting
- installing a roof gutter, air conditioning duct, metal fascia or lighting
- placing pine roof trusses in position on the roof of a low-set house
- performing inspections or tests; or
- installing an electrical connection.

Examples of work that is not light work:

- fixing plaster board sheeting to an internal stairwell void;
- fixing cladding to a gable end of a roof; or
- using a medium or heavy duty angle grinder or circular saw.

Medium Work is a relative term. It relates to **sedentary work** (10 pounds max.) when lifting and carrying objects; walking or standing on occasion, primarily sitting. **Light work** (20 pounds max.) lifting; or carrying 10 pound objects frequently. **Medium work** (50 pounds max.) lifting with frequent lifting and carrying up to 20 pounds; frequent standing or walking. **Heavy work** (100 pounds max.) when occasional lifting, carrying, pushing or pulling.

Minimise means to reduce to the lowest practicable level.

Object includes material.

Overhead platform means a platform designed to provide overhead protection to persons against falling objects.

Perimeter containment screening means a screen:
(a) designed to stop objects falling on persons from a level of a building; or
(b) to redirect a falling object onto a catch platform.

Permit-to-work system includes a written permit which:
(a) authorises certain people to carry out specific work at a certain time; and
(b) sets out the main precautions needed to complete the job safely.

Place includes land, a building, another structure or installation, a road, a vehicle, a tent or marquee, or any other place (even if the place is in a natural or undeveloped state) whether the place is on, under or on the bed of any waters.

Repair means to restore plant to an operating condition, but does not include routine maintenance, replacement or modification.

Risk means the risk of death, injury or illness.

Scrubber is a pollution control device, usually installed on air exhaust systems of machinery.

Self rescuers is a respirator generally designed to be belt-mounted and put on immediately to provide a breath-activated oxygen supply according to demand. Self-rescuers provide a certain duration (minutes) of breathable air under specific work rate conditions. They also need regular inspections and have a maximum storage life limit.

Shotcrete (see also gunite) are two commonly used terms for sprayed concrete. Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a surface.

Static line means a flexible line, to which a lanyard is attached, supported by at least two anchorage points located so that the angle between the horizontal and an imaginary straight line between any anchorage point and the other or nearest anchorage point is:
(a) if the manufacturer of the flexible line has specified the size of the angle—not more than the size specified; or

(b) if the manufacturer has not specified the size of the angle—not more than 5 degrees.

Appendix 4: Ventilation methods and equipment

In considering the design and capacity of a tunnel ventilation system, there are a number of configurations and types of equipment that may be used. Following are of some of the main alternatives.

Ventilation systems may be:

- forced supply
- extraction
- alternating, or a combination of extraction and forced supply, and
- overlap systems.

Fans are used to force or extract air in all the methods above. Fans may be axial flow and:

- single, double or multiple stage
- contra-rotating or non contra-rotating (normally in matched pairs)
- direct driven with motor within the fan casing, or driven with motor outside the fan casing, and
- flameproof type, suitable for use in hazardous atmospheres (including the motors used), or non flameproof type.

Fans are generally designated to be:

- primary fans:
  - located either on the surface or underground, but providing the main ventilation airflow or basic ventilation capacity to the tunnel workings
  - may be centrifugal or axial
  - are electrically powered, sometimes adjustable and often monitored
  - often remain installed in a fixed position throughout the progress of the works.
- auxiliary fans:
  - located underground in the proximity of the workings providing the required flows at the active areas (particularly in blind or dead-end headings)
  - used for regulating the airflows about the tunnel workings
  - may be installed in-line as booster fans to increase the whole airflow in that line
  - are often moved forward as work progresses or ventilation needs alter
  - are generally axial flow and electric, but may be compressed air powered for small short-term airflow applications.

Fans are:

- usually fitted with an evasé[11] if they are exhausting fans to increase efficiency and also with a shroud with a screen to prevent people or materials coming in contact with the blades
- available for special circumstances, such as potentially flammable or explosive atmospheres, with very specific safety features, motor types and requirements

[11] An evasé is a flow diffuser that converts kinetic energy into pressure energy

- selected for the duty required of them to meet the demands of the tunnel work, including equipment, smoke clearance, air velocity requirements, leakage losses, inefficiency and additional future needs, and
- valued for fan pressure and delivered air capacity against resistance or friction in the duct, the excavations or the workings as the case may be.

In any system, because the airflow will otherwise take the route of least resistance, it is directed to the required tunnel areas by a combination of:

- Ducting, including:
  - rigid ducting of steel or fibreglass for the main ventilation lines used in the extraction
  - system for lines under negative pressure (suction)
  - flexible ducting of canvas and polythene for face ventilation, sometimes the main flows
  - for forced air flows under positive pressure (blowing)
  - flameproof, special ducting for hazardous (inflammable or explosive) atmospheres.
- Airways, including:
  - shafts, or ventilation rises conducting air to or from the surface
  - service drives or headings carrying ventilation intake or exhaust air.

The airflow may be regulated by a combination of any or all of the following:

- barricades built of timber, steel, concrete, or bricks
- ventilation doors that can be opened or adjusted
- ventilation regulators that can be adjusted – usually fitted in a barricade
- booster or auxiliary fans to increase flows to selected areas
- brattice or fabric stoppings and brattice wings for directing (low pressure) flows to areas with little air movement, such as pump stations or refuges, and
- altering fans settings to change flows.

Ventilation systems are monitored by measuring a number of atmospheric conditions. This can be done by using instruments including:

- a mercury or aneroid barometer to determine air pressure differences at different points in the system
- wet and dry thermometers to determine the temperature and humidity at any place in the tunnel
- a sling psychrometer to more accurately determine the relative humidity at any place in the tunnel
- a Kata thermometer to determine the cooling effect of air
- a water gauge for measuring air pressure differences (e.g. across a fan and normally used with a pitot tube)
- an anemometer (usually mounted on a stick) to measure the air velocity at any place in the tunnel
- continuous dust and gas monitoring equipment, and
- handheld electronic gas monitors or gas test tubes to determine the concentration of contaminants or other gases in the air.

In a **forced ventilation system,** fresh intake air is drawn from the outside and pushed through ducting (or sometimes through other headings) by in-line fans, to the working face(s). This system has the following advantages, including:

- the air flow can be distributed through flexible ducting that is cheaper and easier to install than rigid ducting
- there is generally no need for an additional overlap system at the face, as a sacrificial section of flexible ducting can be used at the high wear section near the tunnelling activity, and
- activity behind the face, such as trucking or service works in the access do not become a source of contaminants at the working face as the airflow is away from that face.

Some of the disadvantages of this system include:

- all the work activity, apart from near the fresh air discharge points, takes place in 'return' air that has been contaminated with dust or fumes from the working places
- the system relies simply on the dilution of the contaminants or heat to provide a safe environment
- the principle of capturing the contaminants as close as possible to the source is not possible
- flexible ducting tends to suffer more damage and be higher maintenance than rigid ducting
- the system is not readily boosted with in-line fans, and
- auxiliary ventilation of other areas consists of forcing diluted contaminated air into these areas.

In an **extraction ventilation system,** contaminated exhaust air is drawn from the working faces or places through rigid ducting or headings to the surface by the fans, either fitted in-line, into barricades or on shaft tops. This system has the following advantages including:

- the contaminants from the face tunnelling activity are captured into the ventilation system very close to the point of generation
- there is little contact with contaminants from the face activity
- leakage occurs into the duct only
- an overlap system is readily installed at the face to protect ducting and to allow face advance and ventilation extension
- it can be incorporated with dust filter systems behind say, TBMs or road headers
- in-line boosting is readily done by fitting an axial fan in-line, subject to power availability and pressure considerations, and
- auxiliary ventilation of other areas is possible by breaking into the ducting and installing *tee* or *y* pieces.

This system does have some disadvantages that have to be considered including:

- the rigid ducting is harder to repair or replace than flexible ducting
- installation rates are slower for rigid ducting
- costs are higher for rigid ducting, it is harder to store and takes up more room
- more leaks are possible due to the greater number of joints and the need to align and sleeve each joint
- a forcing system or overlap is still required at the face, generally to allow flexibility and to reduce the number of set-ups to install rigid ducting that is ideally done from some distance behind the face
- it is heavier than flexible ducting and can contribute to manual task risks and crush risks
- the "capture zone" in front of the duct inlet is small, and

- the dust, fumes or gases from activity behind the face is drawn to the face first before being exhausted to the surface.

Note: Combination systems of forced and exhaust ventilation are possible to design.

Other: **Overlap** is a description given to a system of:
- using a forcing fan and ducting with the forcing fan set behind the end of an extraction system
- the forcing fan must have a lesser capacity than the extraction capacity at this point – if not, *recirculation* will occur, and
- the forcing fan will push fresh intake air to the face where it will return with the contaminants to the exhaust duct and be removed to the surface.

As ventilation fans are a major source of noise underground, the noise levels generated by the ventilation systems should be limited to those levels determined in the regulation (see section 4.5.1).

Also, common industry practice is to limit the noise levels associated with ventilation equipment to below 100dBA for intermittent exposures.

Various silencers are available or can be built for noise abatement. Fans can also be mounted within sound reducing structures.

Appendix 5: Heat stress and air cooling

Table of air cooling power as a function of air velocity (W/m^2)

Air velocity	**Wet bulb temperature (^{0}C)**					
(m/s)	20.0	22.5	25.0	27.5	30.0	32.5
0.1	176	153	128	100	70	37
0.25	238	210	179	145	107	54
0.5	234	254	220	181	137	87
1.0	321	290	254	212	163	104

Notes:

1. The values given in the above table are the clothing corrected air cooling power at varying wet bulb temperatures and air velocities.
2. The radiant temperature is taken to b equal to the dry bulb temperature, which is typically 10 ^{0}C higher than the wet bulb temperature.

Appendix 6: Table of some hazardous contaminants affecting air quality

Contaminant	Hazard			Buoyancy in air (as a pure substance at ambient conditions) ↑ = Buoyant ↔ = Neutral ↓ = Non-buoyant	Comment/origin
	Toxic?	Asphyxiant?	Flammable?		
Acetylene (C_2H_2)	✓	✓	✓	↑	Due to compressed gas cylinder leak
Ammonia (NH_3)	✓	✓	✓	↑	From concreting or grouting. Leak from refrigeration equipment.
Asbestos				↓	Thermal lagging, old pipes, building materials.
Butane (C_4H_{10})		✓	✓	↓	Due to compressed gas cylinder leak
Carbon Dioxide (CO_2)	✓	✓		↓	Initially buoyant if a hot product of combustion
Carbon Monoxide (CO)	✓	✓	✓	↔	Initially buoyant if a hot product of combustion
Hydrogen Sulphide (H_2S)	✓		✓	↓	From decomposition of organic matter.
Kerosene, Diesel and other low volatility organic solvents	✓		✓	↓	Can usually be handled in confined areas without risk of explosion but can pose a fire and toxicity risk
Methane (CH_4), Natural gas		✓	✓	↑	Natural ground contaminant, or from compressed gas leak
Nitric Oxide	✓			↔	Produced by explosives and engines
Nitrogen Dioxide (NO_2)	✓			↓	Produced by electric arc welding
Oxygen depletion		✓		↔	Oxygen can be consumed or displaced
Oxygen enrichment				↔	Enhanced risk of ignition and fire. Due to compressed gas cylinder leak
Ozone (O_3)	✓			↓	From electric arc welding
Petrol and other highly volatile organic solvent vapours	✓	✓	✓	↓	Fire, explosion and toxic hazard
Propane		✓	✓	↓	Fire and explosion hazard
Respirable Silica				↓	
Sulphur Dioxide (SO_2)	✓			↓	Produced bacterial activity upon dissolved sulphide minerals

Appendix 7: Gases commonly found in excavations and trenches

Gases or fumes encountered	Origin
Methane, hydrogen sulphide	Peaty ground and decaying organic matter
Carbon dioxide, hydrogen sulphide	Filled and made ground
Carbon dioxide, methane, hydrogen sulphide	Reclaimed land and tip fills
Natural gas and carbon dioxide	City streets, leading gas reticulation pipes
Carbon monoxide, carbon dioxide, hydrogen sulphide, sulphur dioxide, methane	Thermal areas, combustion
Petrol fumes, LPG, kerosene	Petrol installation, service stations, underground filling stations.