GUIDELINE

Refuge chambers in underground mines

MIAC

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

GUIDELINE

Refuge chambers in underground mines

MIAC
Government of Western Australia
Department of Mines and Petroleum
Resources Safety

Disclaimer

The information contained in this publication is provided in good faith and believed to be reliable and accurate at the time of publication. However, the information is provided on the basis that the reader will be solely responsible for assessing the information and its veracity and usefulness.

The State shall in no way be liable, in negligence or howsoever, for any loss sustained or incurred by anyone relying on the information, even if such information is or turns out to be wrong, incomplete, out-of-date or misleading.

In this disclaimer:

State means the State of Western Australia and includes every Minister, agent, agency, department, statutory body corporate and instrumentality thereof and each employee or agent of any of them.

Information includes information, data, representations, advice, statements and opinions, expressly or implied set out in this publication.

Loss includes loss, damage, liability, cost, expense, illness and injury (including death).

Reference

The recommended reference for this publication is: Department of Mines and Petroleum, 2013, Refuge chambers in underground mines — guideline: Resources Safety, Department of Mines and Petroleum, Western Australia, 41 pp.

ISBN 978 1 92 1163 94 4

This publication is available on request in other formats for people with special needs.

This publication is also available in digital format (PDF) online at www.dmp.wa.gov.au/ResourcesSafety

Further details of publications produced by Resources Safety can be obtained by contacting:

Resources Safety — Publications
Department of Mines and Petroleum
100 Plain Street
EAST PERTH WA 6004

Telephone +61 8 9358 8002 (general queries)
+61 8 9358 8154 (publication orders)

NRS 13 36 77

Facsimile +61 8 9358 8000

Email ResourcesSafety@dmp.wa.gov.au (general queries)

RSDcomms@dmp.wa.gov.au (publication orders)

Contents

Guidelines

A guideline is an explanatory document that provides more information on the requirements of legislation, details good practice, and may explain means of compliance with standards prescribed in the legislation. The government, unions or employer groups may issue guidance material.

Compliance with guidelines is not mandatory but they could have legal standing if it were demonstrated that the guideline is the industry norm.

Who should use this guideline?

This guideline should be used by anyone planning or conducting underground mining of non-coal resources.

Foreword

This guideline is issued by Resources Safety under the *Mines Safety and Inspection Act 1994*, and has been endorsed by the Mining Industry Advisory Committee.

The Act

The *Mines Safety and Inspection Act 1994* (the Act) sets objectives to promote and improve occupational safety and health standards within the minerals industry.

The Act sets out broad duties, and is supported by regulations, together with codes of practice and guidelines.

Regulations

The Mines Safety and Inspection Regulations 1995 (the regulations) provide more specific requirements for a range of activities. Like the Act, regulations are enforceable and breaches may result in prosecution, fines, or directions to cease operations and undertake remedial action.

Standards

Although specific versions of Australian and other standards may apply under the regulations, references to standards in this guideline are undated and it is good practice to consult the latest versions where applicable.

Application

The provisions of this guideline apply to all underground mines as defined in section 4(1) of the Act, except those extracting coal.

1 Introduction

There is a wide range in the size, location and complexity of underground mines in Western Australia and, consequently, varying degrees of risk associated with these operations. However, there is the potential in all underground mines for an irrespirable atmosphere to be generated as a result of fire, outburst of toxic gases, or concentration of diesel emissions in poorly ventilated headings.

Since oxygen is vital for life, access to breathable air is critical and the bulk of controls must always be aimed at preventing the creation of an irrespirable atmosphere. However, until the sources of this hazard can be eliminated, a means of protecting persons from exposure must be provided.

This guideline provides information on the management and use of refuge chambers designed to protect people from exposure to irrespirable atmospheres underground during an emergency.

Appendix 1 lists the legislative provisions that apply to emergency preparation, the mine atmosphere and refuge chambers.

Appendix 2 provides a glossary of terms and abbreviations used in this guideline.

Appendices 3 to 7 provide additional information on specific issues associated with the use of refuge chambers.

Appendix 8 contains checklists to assist with the management and maintenance of refuge chambers.

2 Purpose of a refuge chamber

2.1 Protection from irrespirable atmospheres

Nature of the hazard

An atmosphere is considered to be irrespirable under conditions where there is an immediate threat to life or the potential for irreversible adverse health effects. The potential for an underground mine atmosphere to become irrespirable due to airborne contaminants derived from fire or other sources or the loss of a fresh air supply is well recognised in the Western Australian mining industry. A refuge chamber can provide a safe haven while waiting for the fresh air supply to be reinstated or a rescue to be mounted.

A comprehensive risk assessment should be undertaken to determine the potential for generation of an irrespirable atmosphere.

Events that can give rise to an irrespirable atmosphere in an underground mine include:

- fire
- explosion – blasting or sulphide dust
- inadequate or loss of ventilation
- flooding
- inrush of mud or tailings
- gas outbursts or intercepts
- extensive collapse of workings
- dust
- contaminated atmosphere (old workings).

Note: Resources Safety has a guideline on how to prevent and mitigate fires in underground mines.

Fire scenarios

Fire is the most common cause of incidents leading to the use of refuge chambers. Potential sources of ignition in an underground mine include:

- heat energy (e.g. high temperature surfaces on engines, exhaust systems, pumps and turbochargers, naked flames from welding equipment, cigarettes and matches)
- electrical energy (e.g. electrical discharge in motors, retarders and transformers, short-circuit arcs, earthing faults, static electricity discharge), induction heating and pyrolysis of tyres
- mechanical energy (e.g. cutting, friction, mechanical impacts, grinding)
- chemical reactions (e.g. self-heating, auto-ignition, exothermic reactions).

The widespread use of diesel-powered and electrical equipment in underground mines means that the provision of mine-wide compressed air reticulation systems has progressively diminished, and the inventory of combustible materials has changed in both type and quantity. Most underground mines now have significant stocks of diesel fuel, hydraulic oil, rubber (as tyres), polyvinyl chloride (as cable sheathing and piping), and resin-based composite materials used for various machine enclosures.

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 underground personnel with an oxygen-generating self-contained self-rescuer (SCSR). These devices allow a person to travel from an endangered position to a safe haven, such as a refuge chamber, where one exists in reasonable proximity. This should be determined through a risk assessment, taking into account the distance to the refuge chamber and the operating time of the self-rescue unit.

Note: Self-rescuers with goggles are recommended to mitigate against eye irritation due to contact with smoke and fumes. Provide goggles where they are not included with self-rescuers.

Inundation and inrush scenarios

Underground refuge chambers that are not designed to cope with the effects of submersion may not function as intended when flooded or engulfed in liquefied materials. It is therefore important that such chambers are located so they are not affected by flooding or other inrush events (see Section 5.6).

2.2 Sustaining life

Chamber status

There are three levels of readiness for refuge chamber operation. In order of increasing independence, these are:

- stand-by
- externally supported
- stand-alone.

When there is no emergency, chambers operate under stand-by conditions. No survival systems are activated. The emergency power pack is kept charged and, if fitted, chamber monitoring and communication systems are enabled.

A chamber is expected to operate under externally supported conditions when there is an emergency but no disruption to normal electrical, pneumatic and potable water services. These services, if provided, are available for the continued support of the chamber.

The stand-alone condition arises when a chamber becomes disconnected from normal external services. The chamber should function with total independence to ensure the survival of its occupants, in the most stress-free manner possible.

Total disconnection from external services is possible during an emergency, and measures should be taken to provide full, independent life support for the occupants of a refuge chamber.

The basic requirements under these fully isolated circumstances are:

- a respirable atmosphere
- an electrical power source to maintain support systems (see Appendix 3)
- a supply of drinking water
- the ability to thermally regulate conditions inside the chamber to avoid heat stress.

Externally supported

Respirable atmosphere

Ideally, the respirable atmosphere should be supplied directly through a dedicated line from an oil-free source on the surface. The compressor supplying the air should be a genuine oil-free unit, providing fresh air.

Where this is not possible, air drawn from a lubricated piston, oil-injected screw or sliding vane-type machine should pass through an air purification system, including pressure regulator, valves and outlet, conforming to Australian Standard AS/NZS 1716 *Respiratory protective devices*. Problems specifically related to hydrocarbon-lubricated units are outlined in Appendix 4.

A risk assessment should be undertaken to ensure appropriate separation of the air intake from possible contaminant sources (e.g. LP gas, ammonia from refrigeration plants, fuel vapours, exhaust emissions)

The air delivered to the chamber must be filtered to AS/NZS 1716 specifications. There should be a system in place (e.g. labelling, colour coding, connection fitting) so that a water line cannot be inadvertently connected to a chamber's compressed air intake.

The entry of breathing air into the refuge chamber may require noise suppression measures (e.g. engineering control, hearing protection), and the rate of flow set to maintain a small overpressure in the chamber, relative to the external atmosphere. Pressure-venting systems matched to the maximum design airflow should be fitted and have immediate self-sealing capability if the external atmospheric pressure exceeds the pressure in the chamber.

Potable water

If a piped supply of drinking water is installed then it should be brought from the surface to a refuge chamber via an independent, dedicated non-metallic pipe installed in a borehole. Alternatively, provide another source of potable water (e.g. bottled water) adequate to supply a full complement of potential occupants for 36 hours (see *Duration of independent services and power* in the next subsection for more information).

Environmental control

When a full complement of people occupies a refuge chamber for a significant period, humidity and temperature can increase rapidly to potentially heatstroke-inducing levels. Refrigerative air conditioning will most effectively counter this potentially serious problem. The power supply must be adequate for the demands of the system (i.e. operating for 36 hours).

Alternative air and water supply

- Steel piping provides a more robust supply route where breathing air and drinking water are directed through normal mine access routes, although steel pipelines passing near a fire will heat up, as will substances passing through them. Where poly-piping is used, there is an inherent risk that the pipe will melt or burn near a fire. The relative merits of using poly-pipe rather than steel need to be assessed.

Power supply

When externally supported, power to the refuge chamber is provided from the mine electrical system. A secure supply of electricity is required to power the means to reduce hazardous gas concentrations to accepted levels inside the chamber, as well as lighting, air conditioning and electronic control systems.

Stand-alone

Respirable atmosphere

Compressed air should be supplied to maintain a positive pressure and respirable atmosphere inside the chamber. There is a risk that the external air supply may be severed and, consequently, an independent means of supply must be provided.

Oxygen (O_2) can be replenished by adding normal air, as long as the source remains available and excess carbon dioxide (CO_2) and carbon monoxide (CO) can be removed (see Appendix 5). Medical-grade oxygen in cylinders, sufficient for a full complement of occupants for 36 hours, should sustain a consumption rate of 0.5 litres per minute per person. The provision of backup supplies from additional oxygen cylinders is recommended. Oxygen candles may be considered as an alternative back-up supply where appropriate.

Potable water

There should be sufficient potable water (e.g. bottled water) maintained at the refuge chamber to adequately supply a full complement of occupants for 36 hours. It is recommended that at least 4.5 litres of water per person be available in the refuge chamber (e.g. 18 litres for a four-man portable chamber).

Environmental control

Environmental controls are required to address the potential for increasing temperature, humidity and potential heat stress. Refrigerative air conditioning will most effectively achieve this for stand-alone refuge chambers. Systems should be robust and of sufficient capacity to handle underground conditions.

Power supply

While power is provided from the mine electrical system under normal circumstances, assume that this source can fail. Provide and maintain a backup supply (e.g. batteries permanently on charge, rotated through service).

Batteries should be externally located to minimise the potential for explosions, fires or exposure to fumes. Protect external batteries and associated wiring by using fire-proof containers and insulation.

Duration of independent services and power

A refuge chamber should be capable of 36 hours of self-sustained operation to allow sufficient time for a rescue to be completed.

Refuge chambers are expected to support a full complement of occupants while operating in stand-alone mode under the worst-case scenario. Such a scenario is provided by a large rubber-tyred vehicle catching fire when travelling in a main intake airway. The danger of re-ignition, a tyre explosion or both may persist for up to 24 hours, and it is deemed unsafe to approach the vehicle during this period (see Resources Safety's guideline on tyre safety).

Although it may be feasible for mine rescue teams to work their way past the burned-out unit and bring the occupants of the refuge chamber or chambers out on foot, it should not be assumed that this would be possible in all cases. One or more of the occupants may be unable to walk and vehicular access may be essential. An additional 12 hours is a reasonable safety margin to allow for the clearance of any obstruction and restoration of normal services.

3 Design and construction

3.1 Robustness

The construction of a refuge chamber should allow for the circumstances under which it will be used and moved. Underground roadways are typically rough, and the equipment fitted inside and attached to the chamber is commonly damaged by vigorous movement, and therefore the chamber and its equipment mountings should be robust.

Refuge chambers are usually positioned by being placed in a cuddy formed in rock using either an integrated tool carrier (ITC) or a load-haul-dump unit (LHD). As a precaution, heavily constructed fenders should be fitted to the chamber to provide some protection from possible rough handling by these machines.

Moveable chambers are usually mounted on skids, allowing them to be moved to different locations in the mine. Attachments to facilitate relocation should be used to minimise possible damage.

3.2 Seals

When in use, a refuge chamber should remain totally sealed off from the surrounding atmosphere. All access doors should fit properly and seals should always be in good condition.

During transport between underground locations, the chamber structure may flex, causing door frames to distort and welded seams to crack. The chamber structure should be sufficiently stiff to resist this flexing and the damage it can cause.

The sealing of a chamber can also be compromised if it is damaged by contact with mine vehicles. The use of substantial bollards or pillars will prevent close access to permanent and semi-permanent chambers.

The integrity of seals can also be affected by concussive effects when units are placed too close to a blast.

A closely fitting door, fully sealed when closed, is the normal means of access to a refuge chamber. Although the control

system is designed to maintain a respirable atmosphere at a small overpressure relative to the external environment, it is possible for the outside pressure to exceed that inside (e.g. during blasting). The vents on the chamber should be immediately self-sealing and the access door should be arranged to open outwards. In this configuration, the seals will tighten if there is an external overpressure and prevent the ingress of external air.

3.3 Secondary means of egress

There is the potential for the main access door to become blocked by a rockfall, vehicle or other obstacle. A secondary means of egress could be considered, with a strongly constructed hatch opening inwards and located as far as possible from the main entrance.

3.4 Pressure equalisation

A pressure equalisation mechanism should be installed to maintain the chamber's internal pressure at a level just above that of the outside.

3.5 Window

Providing a window adjacent to the door of a refuge chamber is a useful and simple feature. It enables visual communication between the inside and outside, and can help lessen the feeling of being enclosed (see Section 8.2). Any window and its retaining structure should be capable of withstanding external overpressure, particularly that caused by blasting.

3.6 Painted surfaces

The interiors of refuge chambers are usually painted white or a pale colour to maximise the effect of internal lighting and provide a reassuring environment. Paints containing hydrocarbon solvents can emit atmospheric contaminants for many years after application. The effects of these emissions on the quality of the breathable atmosphere during a period of extended chamber occupancy have not been fully determined. It is therefore a sensible precaution to use a water-based epoxy paint, which does not emit contaminants when cured.

3.7 Capacity

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

The chamber size should recognise that other personnel such as supervisors, surveyors, geologists and service technicians may also need to use the facility. To accommodate the potential for such people to be in the workings from time to time, either:

- provide a refuge capacity more than double that determined from the size of the locally operating crew alone

or

- implement a system (e.g. shift plan, entrapment tag board) to limit the number of personnel in the area.

Appendix 6 provides guidance regarding visitors.

4 Equipment

4.1 Communications

There must be a secure communications link to a control centre or other manned position. If the link is compromised or the control centre is not manned 24 hours a day, there is the potential for people to abandon refuge chambers if they are not regularly updated on the progress of their rescue.

Communications options include the use of:

- existing leaky feeder systems
- personal emergency devices (PED) that provide an ultra-low frequency, through-the-earth, paging system
- hardwired systems (e.g. optic fibre) capable of carrying high-quality digital information.

Sophisticated high-quality video and audio contacts between a refuge chamber and surface control centre can alleviate anxiety in the occupants and assist in managing the emergency.

Management can also use the communication system to help control inappropriate use of refuge chambers. There are systems to alert control room operators or supervisor stations to personnel entering a refuge chamber so they can initiate steps to establish the reason.

There should be a procedure on the use of the communication system in the refuge chambers, and training provided.

4.2 Gas monitoring equipment

Gas monitoring equipment (e.g. electronic monitors, or pumps and tube sample systems) must be supplied to determine the respirability of the air within the refuge chamber. There should be a procedure and training provided on use of the monitoring equipment, and how to respond.

Note: Gas sampling tubes can have a shorter shelf life in an underground environment if they are not stored according to the manufacturer's instructions.

Specific information relating to carbon dioxide and carbon monoxide is provided in Appendix 5.

4.3 First aid

The level of first aid equipment provided should be commensurate with the number of personnel likely to occupy the refuge chamber and type of injuries likely to be encountered. Oxygen therapy equipment is recommended. Underground mine personnel should be trained in the proper use of the equipment.

4.4 Toilet

Toilet facilities are necessary but need not be overly sophisticated. A self-contained portable unit of adequate capacity is sufficient, bearing in mind the potential number of occupants and a stay of up to 36 hours in the chamber.

Where feasible, consider locating the toilet in a separate airlock compartment for purposes of privacy and odour control.

4.5 Sustenance

In the context of an emergency in an underground mine, starvation is unlikely to be an issue. People can survive for long periods without food but the human body is ill-equipped to cope with dehydration, which affects decision making and reduces coordination — essential skills for survival in an emergency situation. However, the provision of some sustenance may assist with maintaining mental wellbeing.

4.6 Other internal features

Although it may appear desirable to equip a refuge chamber with as many internal features as possible, it should be borne in mind that:

- commonly, internal space is significantly restricted in the underground environment
- the primary purpose of the chamber is to preserve human life, so the genuine functionality of every component of the system should be closely examined and its inclusion justified.

Other items to consider are:

- dry chemical powder (DCP) fire extinguishers
- additional oxygen supplies
- pens and paper
- pack of playing cards
- torch and batteries
- provision for storage of equipment.

5 Location selection and access

5.1 Exposure to hazards

A refuge chamber is perceived as the ultimate place of safety in an underground emergency. Its location should therefore be as secure from hazards as possible. Although the positioning of a refuge chamber is strongly governed by its accessibility to people in need of its protection, any potential susceptibility of its location to the hazards of rockfall, flooding, fire, explosion or damage from mine vehicles should be considered (e.g. cuddy off the main travel ways).

The placement of refuge chambers close to installations such as explosives magazines, fuel storage facilities, transformer stations, mono-pumps or vehicle parking bays should be avoided because they are potential fire sources.

5.2 Distance from working areas

Refuge chambers should be sited near active working areas, taking into account the needs of people working there and potential hazards they face.

Maximum safe distance

A risk assessment should be undertaken to establish the maximum distance separating a worker from a refuge chamber. The assessment should be based on how far a person, in a reasonable state of physical fitness, can travel at a moderate walking pace, using 50 per cent of the nominal duration of the SCSR to reach the nearest refuge chamber.

If it is assumed that workers are equipped with SCSRs of nominal 30-minutes duration, then no-one should be expected to walk more than 750 m to reach the nearest refuge. In reality, this distance will be considerably reduced since an SCSR's duration may be adversely affected by factors such as:

- the wearer's state (e.g. fitness, age, medical conditions, fatigue, agitation)
- physical difficulties encountered (e.g. gradient, negotiating ladderways, climbing escapeways)

- environmental conditions (e.g. temperature, humidity)
- reduced visibility from smoke or dust that limits the rate of progress — this may necessitate the need to get down low or even crawl.

The ventilation practices at a mine may exacerbate the situation with respect to smoke and fumes (see Appendix 7).

Minimum safe distance

A comprehensive risk assessment should be undertaken to determine the minimum safe distance for the location of a refuge chamber near an active working area, taking into account the potential for:

- entrapment
- obstruction to work
- exposure to radiated and convected heat from an underground fire
- damage from the effects of blasting.

These scenarios will be influenced by factors such as:

- geotechnical stability and seismicity
- fuel capacity of plant
- size and composition of vehicle tyres
- installation of fire suppression systems on plant
- proximity to and energy of blasts.

5.3 General access

Housekeeping and the site layout, including the positioning of features such as restricting bollards, lighting and level terrain, should ensure both easy access and adequate protection of the chamber. It is also important that the workforce is completely familiar with the discipline and rules associated with maintaining effective access to the refuge chambers provided and, critically, the reasons why such rules exist. Vehicles and equipment should never restrict access to the refuge chamber.

5.4 Emergency response access

The positioning of a refuge chamber in a modern trackless (i.e. rubber-tyred equipment) mine should take into account the need for vehicular access. There have been international reports of rescue teams arriving at a refuge chamber only to find the route blocked with vehicles abandoned by the very occupants who are in need of rescue. While ready vehicular access is necessary, it is also critical to ensure the chamber is not exposed to damage from being struck by underground mobile plant.

5.5 Accumulation of water

A refuge chamber should not be placed in a location where water can collect in sufficient quantities to pose a risk to workers. Many chambers will be placed deep in the workings to be close to workers who might need them. Pump failure associated with an emergency can cause water to accumulate in the lower areas of a mine. Over a relatively long period of time, such as 36 hours, levels may rise sufficiently to reach deep refuge chamber positions. In this circumstance, it should be recognised that the existing flow of water into the mine can be seriously increased by damaged water mains during an underground emergency.

5.6 Inundation and inrush events

A refuge chamber should not be placed in a location where water, mud or tailings would adversely affect its operation during an emergency.

5.7 Ground conditions

While it is recognised that it may be impossible to locate a refuge chamber excavation in an area free from typical rock mass discontinuities such as faults, fractures and dykes, the susceptibility of these features to seismic activity or other disruptive influences should be thoroughly assessed. Major ground movements associated with seismicity may damage the chamber and its external service equipment, or restrict access to or from the chamber.

The ground support installed in the vicinity of a refuge chamber should be of a high standard, equivalent at least to the standard of permanent support as specified for the mine. Disused stockpile excavations, turning bays, redundant pump cuddies, and ventilation crosscuts are sometimes used as sites for refuge chambers. The original purpose for which these excavations were made might have been designated as being temporary, and the ground support installed may reflect that status. Over time, rock mass conditions can deteriorate locally. Apart from posing a threat to the chamber and its associated equipment, poor ground conditions introduce a hazard to personnel routinely inspecting or servicing the chamber. Refurbishments of such excavations should take into account meshing, shotcreting and re-bolting.

5.8 Identification

The darkness inevitable in the underground environment can be increased to a level of virtual impenetrability by smoke from a fire, making the refuge chamber difficult to locate by people seeking safety. A high-intensity green strobe light fitted close to the door of the chamber can make it easier to find in low visibility conditions. The strobe light should be left on at all times to indicate the chamber's location and operational status.

The probability of finding the chamber door can be significantly improved by a siren sounding close to the door. The siren would be activated by the first person into the chamber and only has to sound during the initial stages of an emergency. The chamber's occupants should be able to turn it off when no longer required.

5.9 Portable refuge chambers

The approach when selecting the location of portable refuge chambers should not be any less rigorous than that for larger, more permanent chambers.

The requirement for the chamber to be connected to mine air, as the initial source of a respirable atmosphere, still applies. Only in the event of losing mine air will the chamber's status change to stand-alone and self-contained air supplies be activated.

Similarly, the need for a portable refuge chamber's location to be signposted by means of a green strobe light is no less important. The ability to locate a refuge chamber is greatly improved through the use of visual and audible beacons.

Four-man portable refuge chambers

Given their limited capacity, there should be a management plan for four-man portable refuge chambers to control the number of personnel working in their vicinity and ensure their seating capacity is not exceeded. Some specific characteristics also need to be considered when deciding the most effective site for their location.

These chambers are designed to be portable and capable of being moved, on what could be a daily basis, so their construction needs to be more robust and their application more flexible. To increase their mobility, some are powered by non-electrical sources (e.g. CO_2-powered). While this degree of self-containment offers some advantages, it also has potential problems (e.g. possible leakage of CO_2 inside the chamber). Although such units do not rely upon a connection to external services to operate, they need to be maintained to the same standard of readiness as electrically powered refuge chambers.

While it might seem desirable to place a small portable chamber as close to the working area as possible, in the event of a fire in the area, radiant heat may be a hazard for potential occupants. Also, what may seem like an ideal location, with respect to providing protection for the workers in one heading, may be compromised by other activities underway near the

chamber. For example, if loading and trucking operations are being carried out near a refuge chamber, a fire on either the loader or truck could prevent access being gained to the chamber by workers from another area.

5.10 Procedures and systems of work

A management plan (see Appendix 8) will help control entry to and the number of personnel in at-risk areas.

Procedures and systems of work for personnel working in single-entry headings should be reviewed in accordance with regulatory requirements (see Appendix 1) to reduce the duration of any potential exposure to irrespirable atmospheres.

There should be systems in place to ensure a safe means of refuge in the event of a fire where personnel are located below active loading, tramming and hauling operations — primarily where trucks or boggers are operating without adequate secondary egress. A site-based risk assessment should also identify any other equipment or conditions that could generate a similar level of risk.

5.11 Avoiding entrapment situations

It is incumbent upon all personnel (particularly supervisors) to be constantly risk-assessing workplace scenarios involving potential entrapment. As conditions change in the work environment, a situation that was previously acceptable may rapidly become dangerous. This particularly applies to personnel operating in remote locations where a portable refuge chamber will provide protection in the event of an emergency.

Regular evaluation of the location of the refuge chamber, especially with regard to the proximity of diesel-powered equipment, should be undertaken to ensure that the chamber is accessible at all times.

Furthermore, limiting the access of both personnel and vehicles to the area should be practised at all times to ensure that the chamber's seating capacity is not exceeded.

Figure 1 shows a poor choice of location for a refuge chamber. While a degree of protection is provided to the jumbo operator in the event of a loader fire, access to the refuge chamber will be obstructed (as well as the potential for chamber occupants to be exposed to extreme heat). If the truck caught fire, anyone trapped between the decline and the development headings would rely on access to the single refuge chamber.

Compared to Figure 1, Figure 2 shows the refuge chamber might be better located towards the unworked end of the development heading, where it provides a safe haven in the event of a fire on any of the three vehicles.

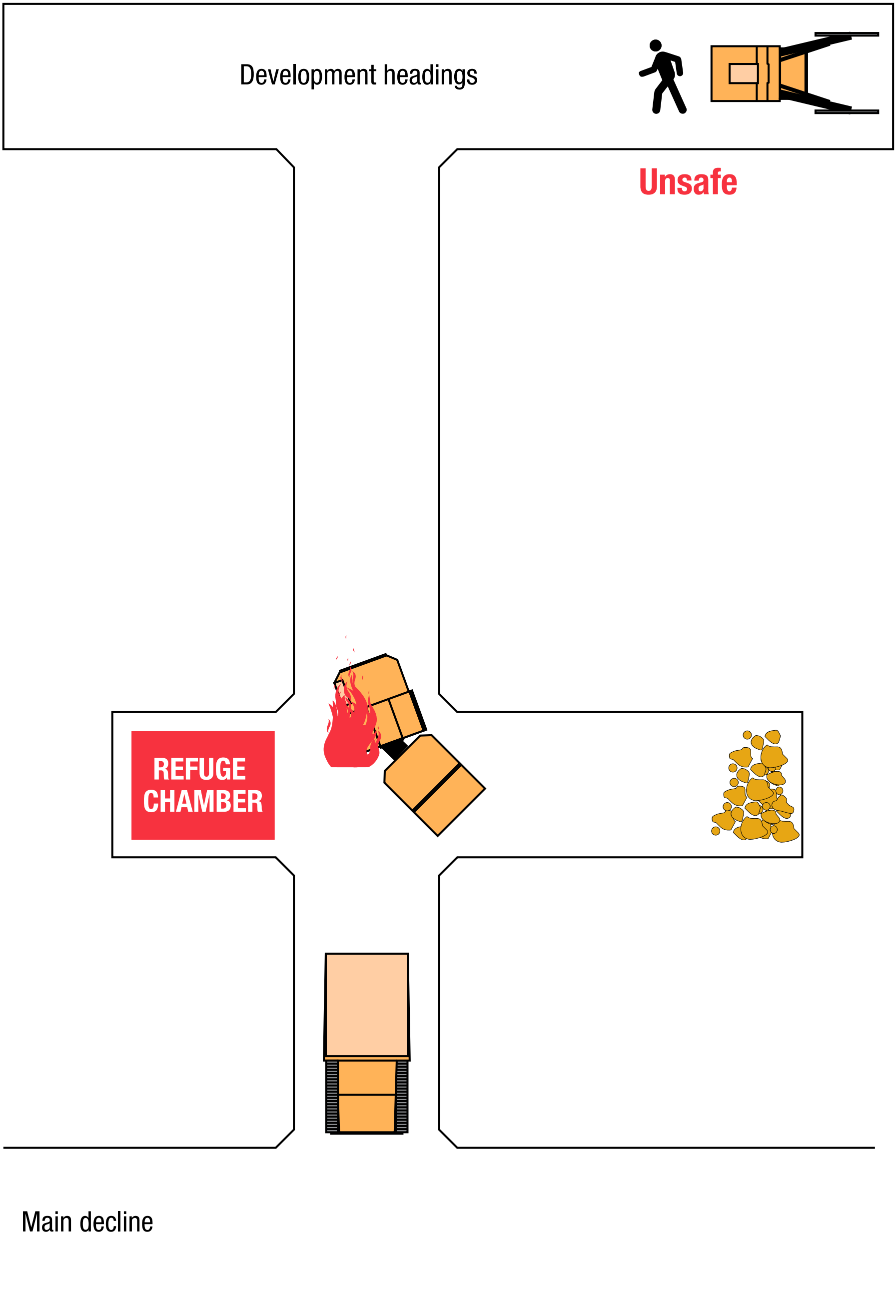

Figure 1 Example of poor refuge chamber location if the loader catches fire

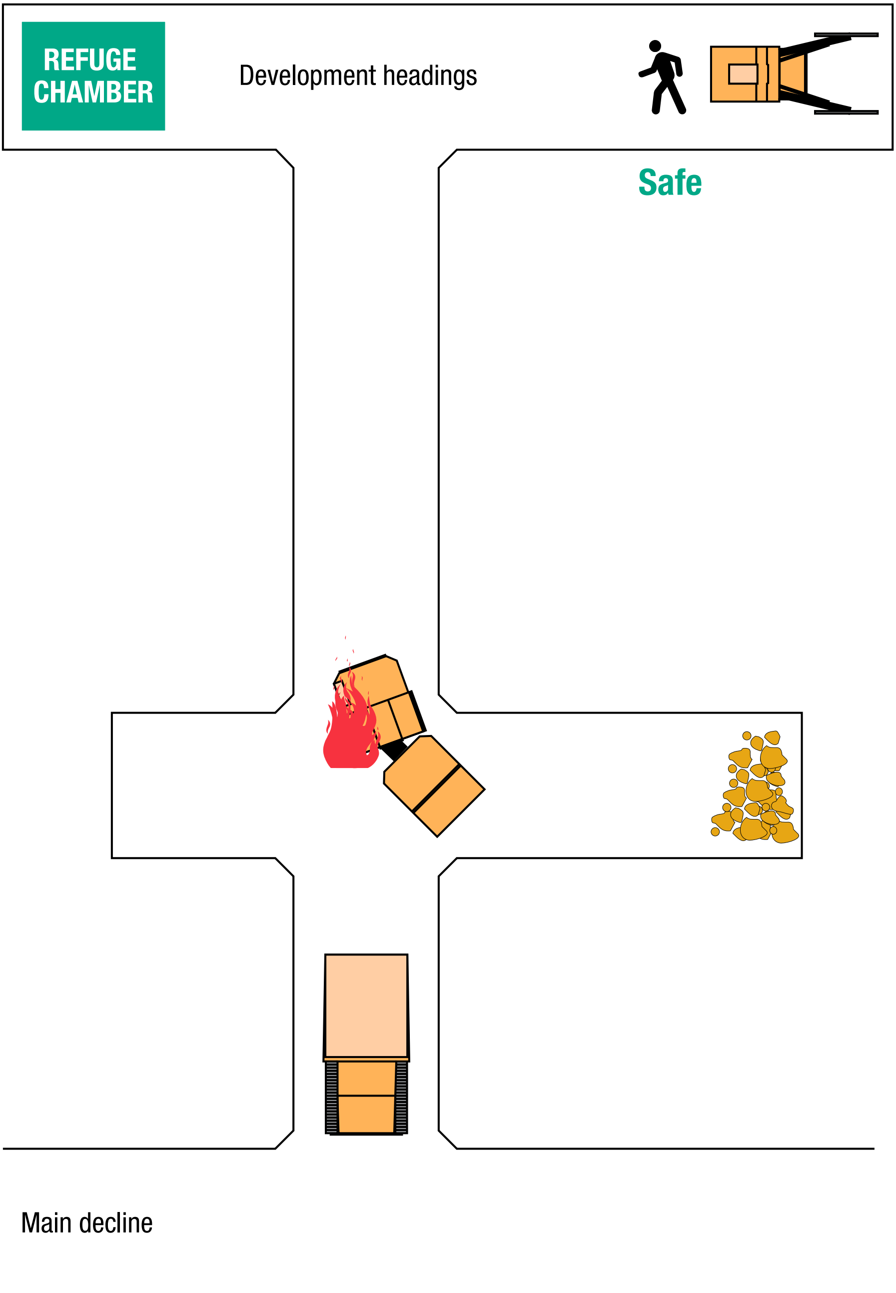

Figure 2 Example of improved refuge chamber location if the loader catches fire

6 Commissioning, inspection and maintenance

6.1 Commissioning and relocation tests

A commissioning test should be carried out when a permanent or semi-permanent refuge chamber is installed for the first time underground, and each time it is moved to a new location. This should include:

- a differential atmospheric pressure test to ensure the integrity of the refuge chamber, including seals and regulators
- a positive pressure test to ensure the operation of vents
- testing the electrical power support in all operational states
  - mains in stand-by and recharge capability
  - independent supply in changeover to stand-alone condition and in change back to stand-by or recharge
- testing the chamber air to ensure that it is free of water and hydrocarbon contamination
- testing other critical systems (e.g. climate control system, oxygen regulator) to ensure they are operational.

6.2 Inspection and maintenance

For a refuge chamber to fulfil its purpose in a mine, it should be ready at all times for immediate, dependable use. This requires an effective and rigorous inspection and maintenance regime.

Based on an assessment of risk factors such as usage, location, and proximity to vehicular traffic and percussion from blasting, chambers should be inspected regularly and basic tests conducted to ensure full functionality. A checklist should be developed based on the manufacturer's specifications (see Appendix 8).

Refuge chambers being moved regularly (e.g. four-man refuge chambers in entrapment situations) should be inspected after each relocation.

Ideally, checks should be carried out daily by people with a vested interest in the correct functioning of the chamber — in other words, people who may have to rely on the chamber for their personal safety or the safety of those they supervise.

All inspections should be recorded and a copy retained within the chamber. This has the advantage of creating an auditable record for scrutiny by management.

Any deficiencies should be reported immediately to the Underground Supervisor or Underground Manager and to the safety department on site, who should arrange for the problem to be dealt with as soon as possible.

Where a deficiency cannot be remedied quickly, underground crews should be informed of the non-availability of the chamber and advised of the alternative arrangements in the event of an emergency.

Responsibility for the ongoing integrity of a mine's refuge chamber or chambers should be clearly established by site management. Any repair or maintenance work must be undertaken by competent persons who are trained and have access to the necessary information and equipment to undertake their duties.

Irrespective of the arrangements for maintenance and repair, the Principal Employer has a duty of care to ensure that sufficient refuge chambers are available and fully functional for use as safe havens by the underground workforce at all times.

7 Training

Basic training on the use of refuge chambers should be included during induction, and cover the variety of chambers used on site.

The effectiveness of training can be increased by using case studies or examples from mining workplaces to demonstrate risk management principles for specific hazards. A refuge chamber could be set up on the surface for hands-on training.

People must be competent in the tasks they are assigned. This means they must have the knowledge and skills necessary to perform the task safely. Competency is gained through training and experience while being supervised or mentored. Assessment of competency should be evidence based and verified before work commences.

There must also be a system to ensure affected personnel are retrained and reassessed whenever systems of work or plant and equipment change, or new systems of work or plant and equipment are introduced.

Training should cover:

- use of the communications equipment
- the procedure for activating life support systems in refuge chambers
- use of first aid resources.

There are also legislative requirements to:

- undertake mock emergencies and drills on a regular basis to identify inadequacies
- use equipment properly, and ensure emergency equipment is not tampered with.

8 Management and supervision

Emergency response plans (reviewed quarterly) should include up-to-date records of the locations and capacities of refuge chambers.

The distribution of personnel relative to chamber capacity, availability and location should be included in the shift plan. The shift supervisor should monitor and control the shift plan, and communicate the plan to the workforce at the start of each shift.

Consider implementing a tag board for controlling access to working areas that is system driven rather than personnel driven (see Section 3.7 and Appendix 6).

9 Other considerations

9.1 Change management

When acquiring new units, review:

- the effectiveness of existing refuges throughout the mine to ensure a common standard
- training and induction requirements.

9.2 Adapting existing facilities

The practice of designating an underground facility such as a lunchroom as a refuge chamber and equipping it for emergency use is one response to the need to provide a safe haven. However, the size and general configuration of such facilities normally mean that they can only be supported by the mine's permanent services (i.e. ventilation, water and electricity). These services may not be immune to interruption and therefore these rock excavations should be equipped as for a manufactured refuge chamber.

9.3 Personal psychological issues

The prospect of having to sit-out the anxiety of a major underground emergency in what is effectively a sealed steel box or rock excavation can be extremely daunting. The presence of injured or otherwise distressed people may exacerbate the situation. Those who have endured this experience, either in a genuine emergency or in test conditions, frequently describe a feeling of being entombed. This is known to create enormous psychological stress.

The physical conditions inside the refuge chamber can have a significant impact on reducing this stress and enabling the occupants to cope. The objective should be to create a reassuring, bright, stable and clean environment. Of primary importance is adequate lighting. From an energy-saving perspective, high-quality fluorescent lighting is sufficient to create a daylight-equivalent environment. High-output light emitting diode (LED) technology is a very reliable, energy-efficient alternative to conventional lighting systems.

Apart from posing the ultimate risk of heatstroke conditions, high temperature and humidity can create a very stressful environment, and therefore the environmental controls discussed in Section 2.2 are important. Another consideration is the installation of deodorising filters to remove the smells that may be associated with intensive occupation of a refuge chamber.

Communication equipment affords a two-way connection with the outside world, and is beneficial in dispelling the anxiety or fear caused by the perception of entombment.

Many chambers now incorporate a porthole-type window adjacent to the primary access door. This means that people inside the chamber can see a person who is attempting to enter it and allow them to assist if necessary. It also means that a view, albeit restricted, of the chamber's immediate surroundings may be available, thereby reducing anxiety. The provision of this limited vision of the chamber's environs is probably sufficient. Larger windows may compromise the engineering integrity of the chamber for little gain.

9.4 Exclusion of flammable materials

Western Australian legislation generally prohibits the use of flammable materials underground, except for specific purposes and then only in limited quantities. There is no functional reason to have flammable materials inside a refuge chamber but it is possible for those seeking refuge to bring such a substance with them, even inadvertently.

Training related to chamber use should emphasise the hazard posed by flammable substances and stress that such materials should not be brought into a refuge chamber, which may have an oxygen-enriched atmosphere. Smoking is prohibited in refuge chambers (see Appendix 1).

10 Further information

DI CORLETO, R., COLES, G., and FIRTH, I., 2003, Heat stress standard & documentation developed for use in the Australian environment: Australian Institute of Occupational Hygienists, Tullamarine, 47 pp.

BRAKE, D.J., 2001, Criteria for the design of emergency refuge stations for an underground metal mine: Journal of the Mine Ventilation Society of South Africa, v. 43(2), p. 5-13.

BRAKE, D.J., and BATES, G.P., 1999, Criteria for the design of emergency refuge stations for an underground metal mine: Proceedings of the AusIMM, no. 304(2), p. 1-7.

BRNICH, M.J., VAUGHT, C., and CALHOUN, R.A., 1999, "I can't get enough air" — proper self-contained self-rescuer usage: US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHSS (NIOSH), Publication no. 99-160, 20 pp.

DEPARTMENT OF INDUSTRY AND RESOURCES, 2005, Tyre safety, fires and explosions — guideline: Safety and Health Division, Department of Industry and Resources, Western Australia, 12 pp.

DEPARTMENT OF MINES AND PETROLEUM, 2013, Prevention of fires in underground mines — guideline: Resources Safety Division, Department of Mines and Petroleum, Western Australia, 42 pp.

DEPARTMENT OF MINES AND PETROLEUM, 2012, Dangerous Goods Safety Bulletin 0212 Managing risk from underground storage of explosives: Resources Safety Division, Department of Mines and Petroleum, Western Australia, 2 pp.

JONES, B., BRENKLEY, D., JOZEFOWICZ, R.R., WHITAKER, D., SHOTTON, J., and BOOTH, A.P., 2003, Use of self-rescuers in hot and humid mines: Health and Safety Executive, Research Report no. 180, 147 pp.

KOWALSKI-TRAKOFLER, K.M., VAUGHT, C., and SCHARF, T., 2003, Judgment and decision making under stress: an overview for emergency managers: International Journal of Emergency Management, v. 1, p. 278-289.

MASHA, 1998, Mine rescue refuge stations guidelines: Mines and Aggregates Safety and Health Association, Ontario, 120 pp.

SAFE WORK AUSTRALIA, 2011, Workplace exposure standards for airborne contaminants: Safe Work Australia, Canberra, 40 pp.

Appendix 1 – Legislative provisions

Mines Safety and Inspection Regulations 1995

Emergency preparation

r. 4.30 Preparation of emergency plan

r. 4.36 Specific emergency precautions required to be taken for underground mines

r. 4.34 Self rescuers in underground mines

Ventilation and control of dust and atmospheric contaminants

r. 9.29 Monitoring of toxic, asphyxiant and explosive gases

r. 9.31(e) Smoking prohibited in certain workplaces

Note: The only authorised versions of the Act and regulations are those available from the State Law Publisher (www.slp.wa.gov.au), the official publisher of Western Australian legislation and statutory information.

Appendix 2 – Glossary

Irrespirable atmosphere – one in which a substance or mixture in an airborne concentration exceeds the relevant exposure standard for the substance or mixture, or where the atmosphere contains less than 18% of oxygen by volume, or both.

Respirable atmosphere – one in which a substance or mixture in an airborne concentration is below the relevant exposure standard for the substance or mixture, and where the atmosphere contains more than 18% of oxygen by volume.

Self-contained self-rescuer (SCSR) – a portable oxygen source for providing breathable air when the surrounding atmosphere lacks oxygen or is contaminated with toxic gases (e.g. carbon monoxide, methane). A SCSR is usually a closed-circuit breathing apparatus with a chemical oxygen generator or a compressed oxygen cylinder and a carbon dioxide absorber.

Appendix 3 – Electrical equipment

All electrical installations must conform to Australian Standard AS/NZS 3000 *Electrical installations* (known as the Australian/ New Zealand Wiring Rules).

Due to the uncertainty of conditions in any particular location underground, all external terminations must have an ingress protection (IP) rating of IP56.

Part 5 of the Mines Safety and Inspection Regulations 1995 refers to extra low voltage (ELV) systems not exceeding 32V alternating current (AC) and 115V direct current (DC). All ELV circuitry must conform to the appropriate provisions of AS/NZS 3000.

All circuit breakers used on the DC side must be selected on the basis of DC current ratings. Where alternate current (AC) ratings are provided, the AC rating must be multiplied by a de-rating factor of 0.6 for DC use.

Select protective devices (e.g. fuses, combination fuse switch units, miniature circuit breakers, moulded case circuit breakers) in accordance with the relevant Australian Standard.

Refer to AS/NZS 2676.1 *Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings – Vented cells* for battery enclosures, and Australian Standard AS/NZS 3011.1 *Electrical installations – Secondary batteries installed in buildings – Vented cells* for battery terminations.

Although not specified in the Mines Safety and Inspection Regulations 1995, Resources Safety's view is that the provision of 240V AC switched socket outlets must be strictly controlled in the underground environment. Only install switched socket outlets where necessary, such as in underground workshops.

Regulations 5.20 and 5.24 of the Mines Safety and Inspection Regulations 1995 require all mains wiring installed underground to be metallically covered and have earth-leakage protection.

Appendix 4 – Respirable air supplied from compressors lubricated by hydrocarbons

With age, piston compressors become susceptible to a condition known as dieseling, whereby the volume of lubricating oil mixed with the air in the compression chamber or chambers is sufficient to support spontaneous ignition and sustain that process until the motive power to the compressor is disconnected. This is a reasonably common condition and should be considered in any risk assessment relating to the supply of air to a refuge chamber underground.

Similarly, the hydrocarbons contained in the compression chambers of oil-injected screw compressors and sliding vane units are known to ignite under specific machine conditions.

Dieseling in relation to piston compressors, and the similar condition that arises in oil-injected screw machines and sliding vane units, can result in the airflow to a refuge chamber being catastrophically contaminated with the irrespirable products of combustion (i.e. smoke). Inspection and maintenance regimes should recognise these conditions and include measures to eliminate the likelihood of breathing air to a refuge chamber becoming contaminated by combustion products.

Appendix 5 – Carbon monoxide and dioxide exposure

A variety of factors will have a bearing on the levels of carbon monoxide and dioxide inside a refuge chamber during an emergency situation.

Factors to be considered when assessing the risk associated with these contaminants include:

- volume and classification of chamber type
- number of people inside the chamber
- ventilation rate (adequate air supply over 36 hours for each person)
- air circulation within the chamber
- frequency of opening chamber doors (particularly without an airlock)
- pressurisation of chamber (positive or negative)

During an underground fire incident, the greatest contribution to carbon monoxide and dioxide levels inside a chamber is likely to be from repeated entries as occupants arrive.

There should be a means to monitor and reduce the chamber concentrations of carbon monoxide and dioxide to accepted standards.

Appendix 6 – Visitors

The occasional presence of large parties of visitors (six or more) in the mine workings is problematic when determining a realistic capacity for a refuge chamber. The number of visitors could require the provision of very large capacity chambers (25 or more occupants) or overpopulation of a smaller chamber. While overpopulation can probably be sustained if the refuge chamber is operating on external power and services, the effective duration of the facility would be severely reduced if the self-contained system was forced to deal with the extra load.

The cost of providing significant additional refuge chamber capacity for possible occasional use is unlikely to be viable. It may be better to assess the likely requirements at each location and determine the number of visitors that can be accommodated with the anticipated workforce. Visitor group sizes could then be restricted accordingly and the duration of visits kept to an acceptable minimum.

For larger groups, consider stopping operations that are likely to cause an emergency (e.g. truck haulage in intake airways) until the visitors have cleared the area.

Appendix 7 – Hazards created by underground ventilation practices

The hazard created by fires, particularly vehicle fires, in underground mines is exacerbated by the widespread implementation of so-called series ventilation systems. Series ventilation systems are used in mining provinces worldwide for development purposes and their implementation is commonly subject to specific regulation. Many mining operations in Western Australia rely solely on such systems, although they do not necessarily represent good practice.

In such systems, a portion of air that has been exhausted in one workplace is successively re-used to partially ventilate others further along the circuit. This virtually ensures that smoke and fumes generated by a fire in any given excavation will affect all others downstream of it.

Appendix 8 – Example checklists

A8.1 Overall equipment

The following checklist provides a quick reference to assess the management of refuge chambers.

☐	The location of refuge chambers is chosen with regard to stability of ground conditions, ease of accessibility, proximity to working areas, and availability of services.
☐	Special consideration is given to situations involving potential entrapment, involving the use of diesel equipment operating between the decline and a working face, where there is only one means of egress.
☐	The potential for fire scenarios is considered when choosing the location for placement of refuge chambers. They should be situated close enough to ensure that they can be reached, using a standard self-rescuer, but not so close that radiant heat becomes a potential hazard.
☐	The capacity of each refuge chamber, the number available, and distribution throughout the mine, is considered in relation to the total workforce and any visitors present, and their distribution throughout the mine.
☐	The management plan ensures the total seating capacity of all available refuge chambers in the mine comfortably exceeds the total number of personnel present in the mine at any given time.
☐	With particular regard to portable four-man refuge chambers, the management plan ensures no more than four persons are in the proximity of a four-man chamber at any time.

☐	The potential for the refuge chamber environment to become contaminated with gases and vapours generated by normal mine activities (e.g. blasting fumes, diesel emissions, gas outbursts) is considered as a result of door being left open or the air supply not being connected to ensure the chamber is not under positive pressure.
☐	The mine compressed air supply is free from contaminants.
☐	Portable refuge chambers are treated the same as permanent installations with regard to signposting (e.g. green strobe light) and connection to mine air.
☐	A regular inspection regime is adopted to ensure all refuge chambers located in the mine are fully functional and ready for immediate use at all times.
☐	Regular drills and training sessions are undertaken to ensure, in the event of an emergency, all mine personnel are fully conversant with the procedure for activating a refuge chamber and maintaining communications.

A8.2 Maintenance

The following checklist provides a quick reference to assess maintenance requirements of refuge chambers.

☐	**Is the chamber easily identified and accessible to the workforce?** For example, signage, green strobe light, reasonable distance from working areas, no obstructions.
☐	**Has the chamber recently been inspected by the manufacturer (or a suitably trained delegate)?** If so, the date of inspection should be displayed on the chamber.

- ☐ **Is the chamber connected to mine air?**

  Check that a compressed air hose is connected to the chamber, via the approved contaminant filtering system, and that the filters are checked regularly as part of a preventative maintenance regime. Confirm that compressed air (not water) is being delivered.

- ☐ **Are the door seals in good condition, and is the door in the closed position?**

  If the door seals are damaged, or the door is left open, contamination of the interior environment may have occurred.

- ☐ **Are batteries holding sufficient charge to provide 36 hours of continuous operation?**

  For example, the unit should be on permanent charge if possible, or rotated through service. Carry out battery conductance tests to identify and replace compromised units.

- ☐ **Upon entering the chamber, does the interior light function, and are any other systems operating?**

  For example, air-conditioner, two-way radio.

- ☐ **Conduct an inventory of the contents of the chamber.**

  For example, communications equipment (telephone or radio), first aid equipment (first aid kit, oxygen therapy equipment, stretcher, blankets), air control valve (if provided), gas monitoring equipment (gas monitor, or hand pump and gas testing tubes), gas scrubbing chemicals, oxygen candle (if supplied), bottled water, portable toilet, toilet paper, and entertainment (playing cards).

- ☐ **Test all equipment, if not already on.**

  For example, does the air-conditioner operate? Can a call be made (and received) on the two-way radio, or telephone? Does the acoustic alarm (siren) function? Is the gas monitor calibrated?

☐	**Check the expiry date of all consumables.** For example, bottled water, scrubbing chemicals and gas testing tubes.
☐	**Is the current copy of the mine emergency plans (including ventilation information) available in the refuge chamber?**
☐	**Are comprehensive chamber activation instructions available for the first occupants?**

Resources Safety
Department of Mines and Petroleum
100 Plain Street
EAST PERTH WA 6004

Telephone	+61 8 9358 8002
NRS	13 36 77
Facsimile	+61 8 9358 8000
Email	ResourcesSafety@dmp.wa.gov.au
Website	www.dmp.wa.gov.au/ResourcesSafety

MIAC

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

RSDSep13_799