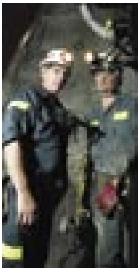
Guideline

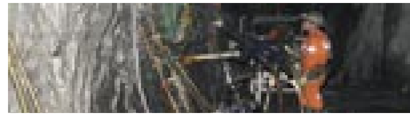





# Refuge chambers in underground metalliferous mines

Department of
Industry and Resources
Safety and Health Division

Guideline



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Safety and Health Division — Publications
Department of Industry and Resources
Mineral House
100 Plain Street
EAST PERTH WA 6004

Telephone: +61 8 9222 3229
Facsimile: +61 8 9325 2280
Email: shd@doir.wa.gov.au


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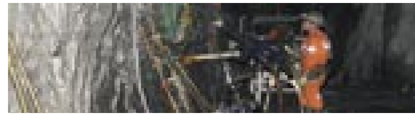


GUIDELINES

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 responsible for the safety of personnel working in underground metalliferous mines.

# Foreword

The *Mines Safety and Inspection Act 1994* established the Mines Occupational Safety and Health Advisory Board (MOSHAB) comprising representatives of employers, employees, unions and government. MOSHAB had the function of advising and making recommendations to the Minister for State Development on occupational safety and health matters concerning the minerals industry in Western Australia.

MOSHAB was also empowered to prepare or recommend the adoption of codes of practice, guidelines, standards, specifications or other forms of guidance for the purpose of assisting employers, employees or manufacturers to maintain appropriate standards of occupational safety and health in the minerals industry.

This guideline was developed through this consultative process, and the views of all parties have been considered. It is issued by the Department of Industry and Resources (DoIR) under the *Mines Safety and Inspection Act 1994*, with endorsement by MOSHAB.

### The Act

The *Mines Safety and Inspection Act 1994* 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 non-statutory codes of practice and guidelines.

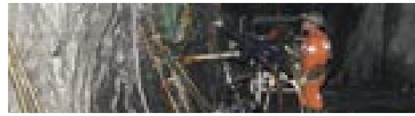
### Regulations

The Act is supported by regulations, which 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.

### Application

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





# 1 Introduction

The purpose of this guideline is to provide guidance on the safe use of appropriate refuge chamber facilities as a part of the response to hazards posed by irrespirable atmospheres underground. Typically, irrespirable atmospheres result from fires in the workings, but they can arise from other causes, including outbursts of gases such as methane or hydrogen sulphide. The provision of refuge chambers is central to any emergency preparedness plan, which in turn is fundamental to the duty of care.

The information presented here is largely based on a series of risk assessments, carried out between 1997 and 2003 at 13 underground mines in Western Australia, that addressed issues relating to the safe use of refuge chambers. The assessments were undertaken by the individual mining operations, independently of DoIR, and the associated documents remain confidential to the respective companies. Other sources of information include fire incident reports from national and international mining authorities, and guidance material produced by various bodies. Material specifications and construction recommendations comply with the appropriate Australian Standard where applicable.

Note that this guideline may not include all factors relating to underground refuge chambers and, in some respects, may not entirely address the individual requirements of every mine.

# 2 Risk statement

All mines to which this guideline applies should be able to demonstrate that their emergency plans provide for the hazards associated with irrespirable atmospheres, and that refuge chambers are being effectively managed. Risk management is essential to prevent fatalities and injuries. It includes:

- identifying the hazards
- assessing the risks
- making the changes necessary to eliminate the hazard or minimise the risk of injury or harm to health.

# 3 Nature of the hazard

The hazards associated with an underground mine atmosphere becoming irrespirable due to contamination from fire or other sources are well recognised in the metalliferous mining industry in Western Australia. The training of miners has traditionally included various techniques of self-preservation using compressed air to create local breathable pockets in "blind" headings, vent tubing, safety helmets, etc. Such techniques date from the period when compressed air was the universal energy source in underground mining, and timber for sleepers, support or shaft furnishings was the principal combustible material.

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

Nearly all underground fires reported in Western Australia occur on vehicles, and may result from:

- high-temperature components on diesel prime movers providing ignition sources for oil sprays from leaking hoses
- sparking from abraded direct-current (DC) power leads damaging fuel lines
- hot surfaces (i.e. > 350°C) such as exhausts and turbochargers
- binding brakes causing grease fires in wheel hubs and igniting tyres.

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 a safe haven. This presumes, of course, that such a safe haven exists in reasonable proximity to the endangered person.

The need for some form of refuge chamber in underground metalliferous mines has long been recognised. Early types were frequently a redundant excavation, which was blocked off to provide an enclosed space where the atmosphere could be overpressured using compressed air sourced from the mine system. This basic model has evolved to incorporate more functionality and increased sophistication. The increasing prominence of diesel-powered trackless equipment and a greater awareness of the needs of the workforce have provided the impetus to develop self-contained chambers that can be readily relocated to support the mining operation as it progresses.

There is uncertainty about whether or not the function of an underground refuge chamber can be extended to cope with a mine flooding or inrush situation — the two worst disasters in recent Western Australian mining history were caused by such events. There appear to be two aspects to this issue:

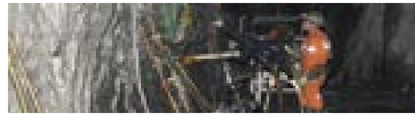
- The design, construction and operation of such a chamber would be akin to that of a small submarine. The potential demands on a submersible chamber would require it to be purpose built because it would be impractical to adapt an existing fire refuge chamber.
- Flooding or inrush events develop so rapidly that there is unlikely to be the opportunity for an underground workforce to move to a designated place of safety before being overwhelmed.

The Mines Safety and Inspection Regulations 1995 contain a provision, reproduced in Appendix 1, that covers refuge chambers.

# 4 Location

### 4.1 Distance from workplace

Refuge chambers should be sited near active workplaces, taking into account the needs of people working there and potential hazards they face. It is recommended that the maximum distance separating a worker from a refuge chamber be based on how far a person, in a reasonable state of physical fitness, can travel at a moderate walking



KEY POINTS — LOCATION OF REFUGE CHAMBERS

- Site near active workplaces.
- Consider needs of workers and potential hazards they face.
- Maximum distance between workplace and refuge chamber should be based on how far a reasonably fit person can travel at moderate walking pace using 50% of SCSR nominal duration.
- Maximum distance should be no more than 750 m.

KEY POINTS — CAPACITY

- Size should recognise potential use by other mine personnel and visitors

  or
- the mine should implement a system to limit number of personnel in area

  or
- both of the above.

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 l/min, 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.

It should be noted that crawling is necessarily slower than moderate walking, and should be allowed for where applicable. Also, the ventilation practices at a mine may exacerbate the situation, as discussed in Appendix 2.

### 4.2 Nominal duration of SCSRs

The nominal duration of an SCSR is established at a specific rate of usage under standard conditions, as detailed in Australian Standard AS/NZS 1716:1994. However, experience and experiments suggest that the rate of consumption is much greater under emergency conditions than might be expected (e.g. Brnich et al., 1999; Jones et al., 2003). Arguments for more or better training, or both, and more frequent simulated emergencies have been advanced and have obvious value. However, the frequency of genuine emergencies involving the use of SCSRs is relatively low, and the financial impost of this training and simulation is significant. The 50% of nominal duration referred to in Section 4.1 attempts to build a realistic and practical safety margin into the duration of SCSRs.

## 5 Capacity

The primary function of an underground refuge chamber 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. 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.

Appendix 3 suggests solutions to address the issue of unplanned usage of refuge chambers by large visitor groups.

## 6 Adapting existing facilities

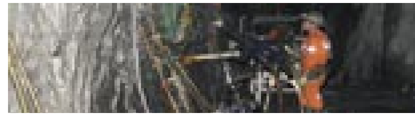
The practice of designating a facility such as a lunchroom as a refuge chamber and equipping it for this purpose is a common, and traditional, response to the need to provide a safe haven. However, the size and general configuration of such a facility normally means that it can only be supported by the permanent services (ventilation, water and electricity) of the mine. In this scenario, therefore, these services must be immune from any interruption. From both technical and financial viewpoints, the equipping of such a resource with independent services is unlikely to be viable.

The lunchroom type of facility can be most useful when either performing as a fresh-air base or associated with one. In normal circumstances, a lunchroom is a semi-permanent installation in a mine, and while it may be readily accessible from most areas, a maximum distance to all workplaces of 750 m is unlikely to be achievable.

## 7 Safety of location

### 7.1 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 hazard as possible. Although the positioning of a refuge chamber is strongly governed by its accessibility for people in need of its protection, any potential susceptibility of



KEY POINTS — ADAPTING EXISTING FACILITIES

- The use of facilities such as lunchrooms as refuge chambers is not recommended — they are better suited as fresh-air bases or associated with such bases.

KEY POINTS — SAFETY OF LOCATION

- Consider accessibility *and* susceptibility to hazards.
- Assess susceptibility of ground conditions to seismic activity and other disruptive influences.
- Take into account the existing water make of the mine and potential fluid sources.

its location to the hazards of rockfall, flooding, fire, explosion or damage from mine vehicles should be considered.

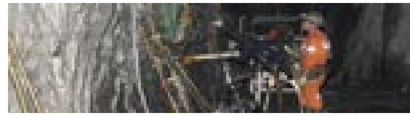
The placing of a refuge chamber close to installations such as transformer stations, explosives magazines, fuel storage facilities or vehicle parking bays should be avoided, as they are potential fire sources.

### 7.2 Ground conditions

While it is recognised that it may be impossible to locate a refuge chamber excavation in an area free from normal rockmass features 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 can damage the chamber, 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 have been variously 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, rockmass conditions can deteriorate locally. Apart from posing a threat to the chamber and its associated equipment, poor ground conditions can introduce a hazard to personnel servicing the chamber on a routine basis, and people attempting to enter the facility for any other purpose.

*Ground conditions should be thoroughly assessed when considering the location of a refuge chamber excavation*



### 7.3 Water make

A refuge chamber should not be placed in a location where water can accumulate 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 collect 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 must be recognised that the existing water make of the mine can be seriously augmented by fluid from water mains damaged during an underground emergency.

## 8 Support of life

### 8.1 Chamber status

Modern refuge chambers typically operate under three separate and complementary regimes — stand-by, externally supported and 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 and must function with total independence to ensure the

KEY POINTS — EXTERNALLY SUPPORTED CHAMBERS

- Respirable atmosphere should be supplied via a dedicated steel line from an oil-free source on the surface.
- Water should be brought in via an independent, dedicated non-metallic pipe installed in a borehole.
- For breathing air and drinking water directed through normal mine access routes, use steel piping.
- The entry of breathing air into the chamber should be subject to noise suppression measures. Set flow rate to maintain a small overpressure.

survival of its occupants, in the most stress-free manner possible.

### 8.2 Stand-by

In this condition the refuge chamber stands ready for immediate emergency use. No critical systems are activated, but all can be immediately functional if required.

### 8.3 Externally supported

#### Respirable atmosphere

Ideally, the respirable atmosphere should be supplied via a dedicated steel 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 must pass through an air purification system, including pressure regulator, valves and outlet, conforming to Australian Standard AS/NZS 1716:2003 (respiratory protective devices). Problems specifically related to hydrocarbon-lubricated units are outlined in Appendix 4.

#### Potable water

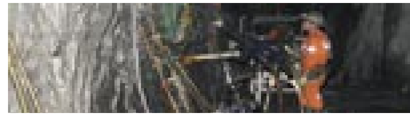
If a piped supply of drinking water is installed then it should be brought from the surface to a refuge chamber via an independent, dedicated non-metallic pipe installed in a borehole.

#### Alternative air and water supply routes

If breathing air and drinking water cannot be fed to a refuge chamber through a dedicated borehole, and instead are directed through the normal mine access routes, only steel piping must be used. Note that if the steel pipelines pass near a fire then they will get hot, as will anything passing through them.

Where available, a mine-wide compressed air reticulation system using steel piping can supply breathing air for a refuge chamber. The air delivered to the chamber must be filtered to Australian Standard AS/NZS 1716:2003 specifications.





Entry of breathing air into the refuge chamber should be subject to noise suppression measures, 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.

### 8.4 Stand-alone

Total disconnection from external services is possible during an emergency, and measures must be taken to provide full, independent life support for the occupants of a refuge chamber. This is probably the pivotal difference between the traditional refuge chamber model and that defined by the needs of current underground mining.

The basic requirements under these fully isolated circumstances are:

- a respirable atmosphere
- an electrical power source to maintain support systems
- a supply of drinking water
- the capability to maintain atmospheric conditions inside the chamber securely below heatstroke-inducing levels.

#### Respirable atmosphere

A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide ($CO_2$) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess $CO_2$ and CO can be removed. There is a risk that the air supply will be severed and, consequently, an independent means of supply must be provided. Medical-grade oxygen in bottles, 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 oxygen candles is strongly recommended.

#### Power supply

Atmospheric scrubber units, lighting, air conditioning and electronic control systems require a secure supply

KEY POINTS — STAND-ALONE CHAMBERS

- Stand-alone chambers must provide full, independent life support for the occupants, with total disconnection from external services possible.
- Basic requirements under fully isolated circumstances are a respirable atmosphere, electrical power source, supply of drinking water and capability to maintain atmospheric conditions.

**KEY POINTS — COMMUNICATION**

- Telephone linkage is not always adequate for communication, as people may abandon a chamber if the link is compromised.
- Alternative forms of radio coverage include leaky feeder systems, personal emergency devices and hardwired systems.
- Communication systems can be used to control inappropriate use of a chamber.

of electricity. In normal circumstances, power can be provided from the mine electrical system. However, it must be assumed that this source can fail and backup must be available. Potential independent emergency power sources are discussed in Appendix 5.

### Potable water

Drinking water is frequently available in Western Australian underground operations from dedicated reticulation systems. Like any pipework system, these can be interrupted in a fire event. It is recommended that sufficient potable water be maintained at the refuge chamber to adequately supply a full complement of potential occupants for 36 hours.

### Environmental control

Simulated emergencies, in which a full complement of people has occupied a refuge chamber for a significant period, indicate that humidity and temperature can increase very rapidly to potentially heatstroke-inducing levels. Refrigerative air conditioning is strongly recommended for both externally supported and stand-alone refuge chambers to counter this potentially serious problem. Inevitably, this will place a heavy demand on the stand-alone power supply, but there are systems available that can cope, and at an acceptable cost.

## 9 Communication

For many years the simple provision of a secure telephone link to a control centre or other manned facility has been regarded as fulfilling the need for communication in an underground refuge chamber. This arrangement has stood the test of time, particularly when refuge chambers and related facilities were very basic. However, 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 do not have communication updating them on the progress of their rescue.

There have been significant developments in underground communication systems in the past decade. Leaky feeder systems based on a special type of coaxial cable can be used to provide radio coverage inside buildings and tunnels. Personal emergency devices (PED) provide an ultra-low frequency, through-the-earth, paging system. Hardwired systems have also become very capable in terms of carrying high-quality digital information. In the future, sophisticated high-quality video and audio contacts between a refuge chamber and surface control centre could alleviate anxiety in the occupants and assist in management of the emergency.

Management can also use communication systems to help control inappropriate use of refuge chambers. There are systems to alert a control room operator or supervisor station to personnel entering a refuge chamber, and initiate steps to establish the reason. Usage control and communication issues are discussed more fully in Appendix 6.

## 10 Internal equipment

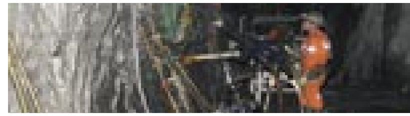
### 10.1 Considerations

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

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

### 10.2 Air and water

After a respirable atmosphere, drinking water is the next most important provision for an underground refuge chamber. Various regulators have specified, commonly in legislation, that a supply of food be maintained, sufficient to provide for a set number of people for a specific period. However, in the context of an underground emergency in a Western Australian mine, hunger 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



**KEY POINTS — INTERNAL EQUIPMENT**

- Consider the restriction of internal space and functionality when assessing the inclusion of equipment.
- Desirable equipment includes a first aid kit, oxy-viva equipment, toilet and table, as well as small items to increase the safety and comfort of occupants.

and reduces coordination — essential skills for survival in an emergency situation.

### 10.3 First aid

A comprehensive first aid kit is an obvious and necessary provision in a refuge chamber. It should include supplies adequate to deal with multiple casualties. The equipment list should include blankets to assist in shock management, and a stretcher. Spine boards are recommended rather than conventional stretchers, and underground mine staff should be trained in their proper use.

### 10.4 Oxy-viva equipment

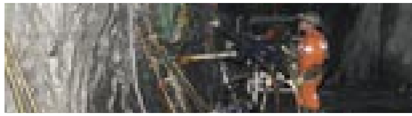
Oxy-viva equipment can provide the benefits of resuscitation, suction and oxygen therapy in one compact unit, operating from a 400 l oxygen cylinder. Its availability would greatly assist people suffering from respiratory or related difficulties. The provision of oxy-viva equipment is recommended subject to the condition that potential occupants of the chamber know how to use it correctly.

### 10.5 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. Technology exists to provide fully private and functional toilet facilities but this significantly constrains internal space, greatly complicates the technical arrangements of the chamber, and increases its cost for little return. Issues of privacy should take second place to effective operation of the refuge chamber.

### 10.6 Table

A table has been identified as a desirable feature inside a refuge chamber, based on a perceived and probably justifiable requirement for the occupants to engage in time-consuming and attention-distracting activities such as card playing. The imperative of efficient use of internal space precludes the provision of a permanently erected table. However, a camping-type table can be effective and is easily set up or dismantled as required.



### 10.7 Eye-wash station

Provision of facilities such as eye-wash stations in the chamber should be considered in the context of space requirement versus functionality. An eye-wash station could be provided outside the chamber for use prior to entry without introducing another space-limiting device inside. Being external, it would also be available for non-emergency situations. If conditions outside the chamber preclude the short-term use of an eye-wash station when occupants are assembling, then it is a minor matter to include disposable eye-wash in the first aid kit inside the chamber.

### 10.8 Other equipment

Other items that should be considered are:

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

*Facilities such as eye-wash stations should be considered carefully, and are probably better provided outside the chamber*

KEY POINT — DURATION OF INDEPENDENT SERVICES AND POWER

- The recommended standard for the minimum duration for which a refuge chamber should be equipped to support life is 36 hours.

## 11 Duration of independent services and power

The question of how long refuge chambers can reasonably be expected to support a full complement of occupants, while operating in stand-alone mode, appears to be the most contentious issue associated with their use. Experience worldwide, from incidents where reliable information is available, suggests a duration of between two and ten hours. However, the set of conditions associated with each of these events is so varied that no clear pattern can be identified to establish an acceptable duration.

The view expressed in this DoIR guideline is necessarily conservative. An appropriate method is to base the recommendation on a 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 (DoIR, 2005).

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. Eight hours is a reasonable period to allow for the clearance of the wreck and restoration of normal services. This brings the total time needed before realistic commencement of rescue operations to 32 hours. DoIR's view is that an additional safety margin of four hours is appropriate, taking the total to 36 hours.

The technologies exist to provide this level of support and it is recommended that the 36-hour standard be adopted as the minimum duration for which a refuge chamber is equipped.

## 12 Personnel psychological issues

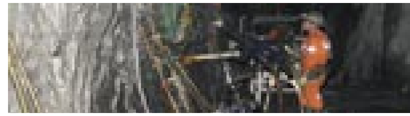
The prospect of having to sit-out the anxiety of a major underground emergency in what is effectively a sealed steel box or rock excavation can be extremely daunting. The presence of injured or otherwise distressed people can exacerbate the situation. Comments from those who have endured this experience, 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. Fluorescent lighting, from an energy-saving perspective, is currently the system of choice. This should be of a high quality and sufficient to create a daylight-equivalent environment. The emergence of high-output light emitting diode (LED) technology now offers a very reliable, energy-efficient alternative to conventional lighting systems, albeit at higher cost. The financial situation may change with time and, hopefully, the use of LEDs will eventually supersede fluorescent systems.

Apart from posing the ultimate risk of heatstroke conditions, high temperature and humidity create a very stressful environment. A refrigerative air conditioner is of great value in this regard. Another measure worth considering is installing deodorising filters to remove the people-generated smells that may feature in an intensive occupation of a refuge chamber.

Communication equipment such as that described in Appendix 6 affords a two-way visual and audio connection with the outside world, and would be 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, and larger windows may compromise the engineering integrity of the chamber for little gain.



KEY POINTS — PERSONNEL PSYCHOLOGICAL ISSUES

- The feeling of being entombed in a refuge chamber can cause enormous stress.
- Adequate lighting, temperature control, deodorising filters, communication equipment and a small window can all help occupants to cope.

KEY POINTS — ELECTRICAL EQUIPMENT

- All electrical installations must conform to Australian Standard AS/NZS 3000:2000.
- External terminations must have an ingress protection rating of IP56.
- All circuit breakers used on the DC side must be selected on the basis of DC current ratings.
- Battery enclosures must conform to Australian Standard AS/NZS 2676.1:1992.
- Battery terminations must conform to Australian Standard AS/NZS 3011.1:1992.
- The provision of 240V AC general power outlets should be strictly controlled in the underground environment.
- The use of braided or armoured cable is encouraged when wiring underground installations.

# 13 Electrical equipment

All electrical installations must conform to Australian Standard AS/NZS 3000:2000. Due to the uncertainty of conditions in any particular location underground, all external terminations must have an ingress protection (IP) rating of IP56.

Direct current (DC) extra low voltage (ELV) refers to systems operating at 50V and less. All ELV circuitry must conform to the appropriate provisions of Australian Standard AS/NZS 3000:2000.

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.

Protective devices are selected from the following, in accordance with the indicated standard:

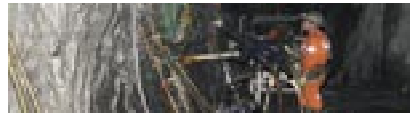
- fuses — Australian Standard AS/NZS 1775:1984
- combination fuse switch units incorporating high rupturing capacity (HRC) fuses — Australian Standard AS/NZS 1775:1984
- miniature circuit breakers (MCB) — Australian Standard AS/NZS 3111:1994
- moulded case circuit breakers (MCCB) — Australian Standard AS/NZS 2184:1985.

Battery enclosures must conform to Australian Standard AS/NZS 2676.1:1992. Battery terminations must conform to Australian Standard AS/NZS 3011.1:1992.

Although not specified in the Mines Safety and Inspection Regulations 1995, DoIR's view on the regulation of electricity is that the provision of 240V AC general power outlets (GPOs) should be strictly controlled in the underground environment. GPOs should only be installed where necessary, such as in underground workshops. The presence of a GPO in a refuge chamber, particularly if in an emergency situation it can draw power from the stand-alone system, has the potential to prematurely exhaust the available power.

The use of braided or armoured cable is encouraged by DoIR when wiring underground installations. It is accepted that there is a cost penalty but it is not great and the safety benefits are significant.





# 14 Access and site layout

## 14.1 Vehicular access

The positioning of a refuge chamber in a modern trackless (i.e. rubber-tyred equipment) mine should take into account the need for immediate vehicular access at all times and under all circumstances. 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 that the chamber is not exposed to damage from being struck by underground mobile plant.

## 14.2 Lighting

The darkness inevitable in the underground environment can be increased to a level of virtual impenetrability by smoke from a fire. This can make the refuge chamber

*A siren is essential to increase the probability of finding the refuge chamber in extreme conditions. Collimating the sound helps intending occupants to locate the door*

### KEY POINTS — ACCESS AND SITE LAYOUT

- Consider the need for immediate vehicular access at all times and under all circumstances.
- Use restricting bollards, lighting and signage to assist in ready vehicular access and prevent damage by underground mobile plant.
- Ensure workforce is familiar with effective use of refuge chambers.
- A high-intensity strobe light near the chamber door can expedite the location of the chamber in smoky conditions.
- A siren with collimated sound near the chamber door increases the probability of finding the chamber door in low visibility conditions.

difficult to locate by people seeking safety. A high-intensity strobe light fitted close to the door of the chamber can make it easier to find in smoky conditions.

### 14.3 Siren

The probability of finding the chamber door can also be significantly improved by a siren sounding close to the door. By placing the siren between two vertically mounted heavy metal plates, the sound can be collimated such that the loudest signal is heard directly in front of the door. The siren would only have to sound during the initial stages of an emergency, and the chamber occupants should be able to turn it off when no longer required.

### 14.4 Layout

The site layout, including positioning of features such as restricting bollards, lighting and signage, should ensure both easy access and adequate protection of the chamber. Most important, however, is making sure the workforce becomes thoroughly familiar with the discipline and rules associated with effective use of the refuge chambers provided and, critically, the reasons why such rules exist.

## 15 Design and construction

### 15.1 Robustness

The construction of a refuge chamber should allow for the circumstances in which it will be used. Moveable chambers are usually mounted on skids, allowing them to be towed or pushed to different locations in the mine. Underground roadways are typically rough, and the equipment fitted inside and attached to the chamber is commonly damaged by the vigorous movement, and therefore the chamber and its equipment mountings must be very robust. Refuge chambers are usually positioned by being pushed into a cuddy formed in rock using either the bucket of 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.



### 15.2 Seals

When in use, a refuge chamber must remain totally sealed off from the surrounding atmosphere. All access doors must fit properly and seals must always be in good condition. During transport between underground locations, the chamber structure may flex, causing doorframes to distort and welded seams to crack. The chamber structure should be sufficiently stiff to resist this flexing and the damage it can cause. After a chamber has been relocated, all seals should be fully tested before it is returned to service.

The sealing of a chamber can also be compromised if it is damaged by contact with mine vehicles. Such incidents normally occur when items of plant manoeuvre nearby. The placing of substantial bollards or pillars inhibiting close access to a chamber is a worthwhile precaution.

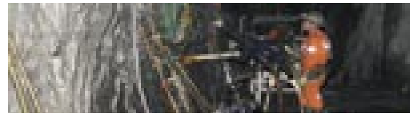
A closely fitting door, fully sealed when closed, is the normal means of access to a refuge chamber. Although the control system is designed to maintain a respirable atmosphere at a small overpressure relative to the external environment, it is possible for the outside pressure to exceed that inside (e.g. during blasting). The vents on the chamber must 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.

### 15.3 Secondary means of egress

Some risk assessments have identified the risk that the main access door could 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.

### 15.4 Pressure equalisation

The system controlling the internal atmosphere should be capable of maintaining the chamber pressure just above that of the outside. To maintain this relationship, a pressure equalisation mechanism should be installed.



### KEY POINTS — DESIGN AND CONSTRUCTION

- Moveable chambers, including equipment mountings, must be robust.
- All access doors must fit properly and seals must always be in good condition.
- A secondary means of egress should be considered.
- A pressure equalisation mechanism will maintain the chamber pressure just above that of its surroundings.
- If fitted, windows and retaining structures must be able to withstand external overpressure, particularly from blasting.
- Use a water-based epoxy paint to prevent contamination of the chamber atmosphere.
- Emphasise the hazard posed by flammable materials and ensure their exclusion from refuge chambers.

### 15.5 Window

The provision of 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, as discussed in Section 12. If fitted, a window and its retaining structure must be capable of withstanding external overpressure, particularly that caused by blasting.

### 15.6 Painted surfaces

The interiors of refuge chambers are usually painted white or another 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. Consequently, it is a sensible precaution to use a water-based epoxy paint, which on curing does not emit contaminants.

### 15.7 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 a person seeking refuge to bring such a substance with them, even inadvertently. Training related to chamber use should emphasise the hazard posed by the presence of flammable substances and stress that they should not be brought into a refuge chamber.

## 16 Maintenance

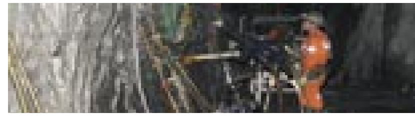
It is obvious that for a refuge to fulfil its purpose in a mine, it must be ready at all times for immediate, dependable use. This requires an effective and rigorous inspection and maintenance regime.



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 carried out to ensure full functionality. A checklist should be developed based on the manufacturer's specifications. 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. Ideally, checks should be carried out daily by people with a vested interest in the correct functioning of the chamber — people who may have to rely on it for their personal safety or the safety of those they supervise. Any deficiencies should be reported immediately to the Registered Manager and senior engineer on site, who should arrange for the problem to be dealt with as soon as possible.

Where a deficiency cannot be remedied quickly, the availability of alternative facilities must be considered. At the very least, underground crews must 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. Clearly, any repair or maintenance work will devolve to the engineering personnel, who should have




*No flammable materials should be kept in or brought into a refuge chamber*

KEY POINTS — MAINTENANCE

- Refuge chambers must be ready to provide a safe haven at all times.
- Institute an effective and rigorous inspection and maintenance regime to ensure full functionality.
- Any deficiencies should be reported immediately to the Registered Manager and senior engineer on site.
- Clearly establish who is responsible for the ongoing integrity of refuge chambers.

KEY POINTS — TESTING

- When a chamber is installed underground for the first time
  - undertake a full vacuum test to check sealing arrangements
  - test electrical power support in all operational states.
- Full audits are recommended at least annually.
- The functionality of chambers is most vulnerable after relocation, and they should be checked carefully after each move and preferably six-monthly.

access to the necessary information and equipment to undertake their duties.

The reliance on contractor-provided services, common in Western Australian mines, can pose a difficulty for the maintenance of refuge chambers. Some chamber manufacturers do provide maintenance services, but these are typically only available at quarterly or even longer intervals. Day-to-day problems that affect the chamber's integrity cannot be left until the next routine service opportunity. On a mine where contract maintenance personnel are engaged in looking after specific types of equipment, often specialising in one manufacturer's products, the situation may arise where no specialist service capability is available for unusual items such as refuge chambers. This is particularly so for electrical problems, as many sites do not employ a permanent electrical technician but instead rely on visiting contracted personnel.

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

## 17 Testing

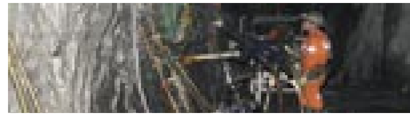
A commissioning test should be carried out when a refuge chamber is installed for the first time underground. This should include:

- a full vacuum test to ensure the integrity of all seals
- testing electrical power support in all operational states
  - mains in stand-by and recharge capability
  - independent supply in change over to stand-alone condition and in change back to stand-by or recharge.

The condition of the refuge chamber should be fully and regularly audited. This should take place at six-month intervals, but in any event within twelve months.

Operational experience indicates that the functionality of a refuge chamber is most vulnerable during relocation. A full commissioning check should be undertaken as soon as possible after each move.

## 18 Further information

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*When considering the capacity of the refuge chamber, remember to include potential visitor numbers or a scheme to restrict group size, duration of visit, or both*

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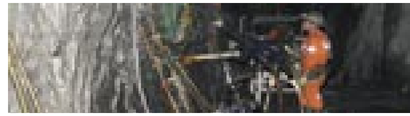
# Appendix 1 — Legislative requirements



**Mines Safety and Inspection Regulations 1995**

**Specific emergency precautions required to be taken for underground mines**

4.36. (1) This regulation applies to any of the following potential incidents —

(a) a fire;
(b) an accidental explosion (including a sulphide dust or coal dust explosion);
(c) a failure of the primary ventilation system;
(d) flooding;
(e) an inrush of mud or tailings;
(f) an inrush or outburst of gas; or
(g) the extensive collapse of workings.

(2) The principal employer at, and the manager of, an underground mine must ensure that, so far as is practicable, the following things have been done to ensure the safety of persons working underground in the mine in the event of a potential incident to which this regulation applies —

(a) an alarm system has been installed and a procedure has been established for activating the system;
(b) a procedure has been established for the prompt notification of rescue and fire fighting teams;
(c) a procedure has been established for evacuating persons working underground;
(d) fire refuge chambers and fresh air bases are provided for persons working underground;
(e) provision has been made for the safety of drivers of winding engines at underground shafts;
(f) all employees are adequately trained and retrained in emergency procedures and the use of emergency equipment and facilities; and
(g) emergency drills have been conducted on a regular basis.

**Penalty: See regulation 17.1.**

*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 — Hazards created by underground ventilation practices

The hazard created by underground fires, particularly vehicle fires, in Western Australian mines is exacerbated by the widespread implementation of so-called series ventilation systems. 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.

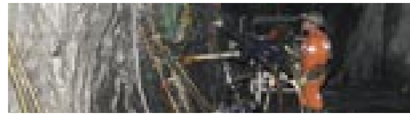
Series ventilation systems are used in mining provinces worldwide for development purposes and their implementation is commonly subject to specific regulation. Many mining operations in Western Australia rely solely on such systems, although they do not necessarily represent good practice.

## Appendix 3 — Unplanned usage of refuge chambers by visitor groups

The occasional presence of large parties of visitors (six or more) in the workings of a mine 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. A better solution is 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, consideration should be given to stopping operations that are likely to cause an emergency (such as truck haulage in intake airways) until the visitors have cleared the area.



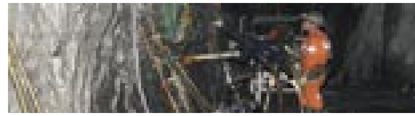


## Appendix 4 — Respirable air supplied from compressors lubricated by hydrocarbons

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 must be considered in any risk assessment relating to the supply of air to an underground refuge chamber.

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 an underground refuge chamber being catastrophically contaminated with the irrespirable products of combustion, collectively called smoke. Inspection and maintenance regimes must recognise these conditions and include measures to eliminate the risk of breathing air to a refuge chamber becoming contaminated by combustion products.



# Appendix 5 — Potential independent emergency power sources

**Independent supply**

A second, totally independent power supply via cable can be installed in an escape system, shaft or dedicated borehole.

**Battery powerpack**

Power can be provided by a dedicated battery powerpack, usually rechargeable from the mine main electrical system. From a safety, cost and utility perspective, this would typically be a sealed lead acid system located *in all cases outside* the chamber.

**Electrical generators**

Diesel engines, fuel cell units, compressed air motors, cryogenic power packs, conventional gas turbines, and closed-cycle units such as Brayton cycle gas turbines have been proposed as prime power sources.

*Diesel engines* and some *fuel cell units* require external (atmospheric) oxygen in order to operate. In the event of a major underground fire, the oxygen supply can be compromised unless provision is made for an independent source. The air consumption of a small two-cylinder diesel engine is such that it could evacuate a volume equivalent to that of a standard sea container in less than two hours. It must be appreciated that this volume is "whole air", not just oxygen.

An internal combustion engine, unlike the human body, cannot return the unused components of atmospheric air to its environment uncontaminated. Diesel engines do not operate effectively, if at all, in oxygen-deficient atmospheres or in environments where there are significant quantities of gases such as methane or carbon monoxide. Research in the oil and gas industries has shown that ingesting combustible gases with intake air can mistime a diesel engine, and that mistiming can give rise to a flame path to atmosphere via the intake valves.

A number of refuge chambers already in use in Western Australian mines are equipped with emergency diesel power, and more are being proposed. In the case of some units, a solution to this hazard is to draw the intake air from the refuge chamber. A means of replenishing the "whole air" supply to the chamber from an uncontaminated source must be provided, but how this is achieved is unclear. The use of such systems is therefore not recommended.

Although exceptionally reliable in operation, *compressed air motors* are clearly only as dependable as the supply of compressed air. In the circumstances surrounding an underground fire, the compressed air supply is very vulnerable to disruption and thus the use of this type of system is not recommended.

*Cryogenic* (liquid nitrogen) *power packs* have enjoyed varying fortunes as emergency energy sources. While they have been shown to be quite effective, the storage systems and associated support units require a high level of maintenance and are relatively expensive.

An electric generator driven by a *gas turbine*, in turn powered by a *closed-cycle system* such as the Brayton cycle, which draws energy from a high-temperature source such as molten salt, could conceivably be used to support a refuge chamber in full stand-alone mode. However, in the current context of Western Australian mines, such an arrangement would be:

- very expensive
- exotic — it is likely that little, if any, knowledge of the operation of such systems is available in the Western Australian mining industry.

While innovation is to be encouraged, it is recommended that the implementation of such systems be approached with great caution.

# Appendix 6 — Usage control and communication issues

The relatively sophisticated support systems proposed in this guideline require continuous supervision and maintenance to ensure that they remain reliable. Unauthorised and non-emergency (including training) use can reduce the working life of the lighting and stand-by systems, and, in time, pose a hazard to true emergency use. A modern refuge chamber, operating in the stand-by condition, presents an attractive environment underground. Western Australian experience shows that chambers are used by the workforce for purposes other than those relating to an emergency. Most disturbing are reports that chamber facilities are being used to provide an "oxygen fix", with inspectorate reports of chamber oxygen inventories being up to 50% deficient where no emergency use has been reported or identified. This activity results in serious degradation of the chamber's ability to provide adequate support in an emergency, and is an issue for mine management to address under its duty of care.

There are currently three start-up regimes under which refuge chambers can be operated:

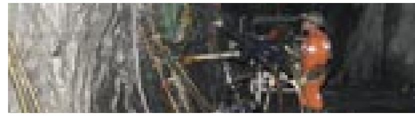
- manual
- automatic
- remote.

**Manual start-up**

Manual start-up by first occupant(s) requires that all potential occupants are thoroughly trained in the process. This also presumes that the training is sufficiently robust to ensure that a person, possibly in a very agitated state, affected by smoke or fumes, or injured in some way, can reliably initiate and carry through the start-up process correctly. Clear instructions should be posted in obvious places to assist the start-up.

It should be noted that this form of start-up will not preclude unauthorised or non-emergency use of the chamber.





**Automatic start-up**

Automatic start-up by devices sensing the presence of people can readily be provided. The easy availability of reliable passive infrared (PIR) devices, at reasonable cost, makes implementation of such systems comparatively simple. Again, however, a difficulty arises with unauthorised or non-emergency use of the chamber.

**Remote start-up**

Given that most Western Australian underground mines are equipped with either leaky feeder or PED communication systems, remote start-up from a control centre following recognition of an emergency underground could be readily implemented. These systems display increasing capability and reliability while offering significant benefits in terms of the control of a number of underground functions. They have already been successfully used to activate remote features.

The main difficulty with these systems lies in how and when they would be activated. If control room personnel are to be responsible for activating the underground response to an emergency then they need access to a wide-ranging, robust and rigorous monitoring and warning system. Two-way communication systems such as leaky feeders allow rapid and dependable transmission of information. The conditions of a perceived underground emergency, as conveyed via whatever communication system is available, will depend on the knowledge of the person doing the reporting, his or her state of anxiety and physical condition, and other factors. There is a risk of false alarms being raised or major problems being understated.

A desktop computer, monitor, keyboard and monitoring digital video camera are comparatively cheap and increasingly common features in underground workplaces. If a computer is connected to a control centre via a secure hard-wire link, visual observation and contact can be maintained, and the advantages of automatic start-up, control room alert and continuous non-emergency monitoring can be exploited.

The availability of a secure, real-time visual up-link in a refuge chamber has significant benefits in the event of a genuine emergency. A chamber-based computer can be used to monitor the ongoing status of the various systems and visual, real-time chamber use. Although the energy requirements of such a system would need to be assessed, its implementation would ensure that an underground refuge chamber maintains its primary function and protect against unauthorised or non-emergency occupancy. Surface-based control room staff would become aware of emergency situations underground as quickly and comprehensively as possible.





Department of
**Industry and Resources**
Safety and Health Division

Mineral House
100 Plain Street
EAST PERTH WA 6004

Telephone: +61 8 9222 3092
Facsimile: +61 8 9325 2280
Email: shd@doir.wa.gov.au
Website: www.doir.wa.gov.au