Model Work Health and Safety Regulations for Mining - Public Comment Response Form

Individual/Organisational name: MineARC Systems	
Regulations Chapter 9: Mines	
Part 9.1	
Regulation	**Comment**
Part 9.2	
Regulation	**Comment**
Part 9.3	
Regulation	**Comment**
Other Comments	

Codes of Practice	
Roads and Other Vehicle Operating Areas	
Section/page number	**Comment**
Managing Naturally Occurring Radioactive Materials in Mining	
Section/page number	**Comment**
The Mine Records	
Section/page number	**Comment**

WHS Management Systems in Mining	
Section/page number	**Comment**
Inundation and Inrush Hazard Management	
Section/page number	**Comment**
Emergency Response in Australian Mines	
Section/page number	**Comment**
7.14 Change-Over Stations	Please see attached document. 7.14 Procedures for Changeover Stations.
7.15 Refuge Procedures	Please see attached document 7.15A Refuge Procedures for Hard rock mines and 7.15B Refuge Procedures for Coal mines.
Strata Control in Underground Coal Mines	
Section/page number	**Comment**
Ventilation of Underground Mines	
Section/page number	**Comment**
Survey and Drafting Directions for Mine Surveyors	
Section/page number	**Comment**

Health Monitoring	
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Mine Closure	
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Ground Control in Open Pit Mines	
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FINAL changeover COP submission

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Public comments on Draft Code of Practice
EMERGENCY RESPONSE AT AUSTRALIAN MINES

INTRODUCTION

Established in 1999, MineARC Systems is now the global leader in the manufacture and supply of emergency refuge chambers to the underground mining, tunneling, nuclear and chemical processing industries.

Emergency refuge chambers form an integral part of an underground mine, tunnel, nuclear or chemical operation's wider Emergency Response Plan (ERP). Fires, explosions, rock-falls, flooding, and the release of smoke and other forms of toxic gas are the types of industrial incidents that occur all too frequently, (refer to appendix 2) despite the high levels of planning and safety precautions in place.

In these types of emergencies, when evacuation is no-longer safe or practical, emergency refuge chambers are designed to provide a safe and secure 'go-to' area for personnel to gather and await extraction. MineARC refuge chambers have been successfully used around the world in multiple mine and tunneling emergencies to save lives. Refer to appendix 2.

Inside a standard MineARC refuge chamber a number of vital life support systems combine to create a safe and secure ongoing environment for occupants, including; oxygen supply, carbon dioxide (CO_2) and carbon monoxide (CO) scrubbing, cooling and gas monitoring.

Today MineARC has offices and manufacturing facilities in Perth, Western Australia; Santiago, Chile; Fushun, China; Pretoria in South Africa and Dallas in the United States, as well as a strong distribution network worldwide. In all, MineARC manufactures refuge chambers for operations in over 30 countries world-wide.

All MineARC refuge chambers comply with the highest international industry regulations, standards and guidelines.

MineARC hard-rock refuge chambers comply in full with the West Australian Department of Mines & Petroleum (DMP) industry Guidelines. MineARC hard-rock refuge chambers are also European CE and Australian C-Tick certified and is ISO9001 certified.

MineARC Systems would like to submit the following comments and recommendations for:
Draft Code of Practice – 7.15 Refuge Procedures - EMERGENCY RESPONSE AT AUSTRALIAN MINES

7.15B REFUGE PROCEDURES FOR COAL MINES

7.15.1 BACKGROUND

During an emergency situation, the first priority for all underground personnel should be to exit the coal mine via predetermined egresses and escape routes. However, emergency situations have occurred in the past, and remain likely to occur, in which personnel have become cut off and/or found it difficult to exit the mine.

Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas (such as methane) can block escape routes and leave personnel injured or simply overwhelmed. Examples of incidents that have occurred can be found in appendix 2 of this document.

In an emergency situation personnel will be required to don breathing apparatus (self contained self rescuers (SCSR)), as smoke and other noxious gases contaminate the air. Typically, SCSR's only provide 30 minutes breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed with no impediments (refer appendix 11). With many underground networks extending over a number of kilometres, exiting the mine during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury, and for those who may be assisting them.

The need for a changeover of breathing apparatus whilst exiting the mine during an emergency situation is therefore a distinct possibility. Further, this changeover may be required within a non-secure (irrespirable) environment. Personnel may also be suffering from disorientation, shock, and a potential lack of visibility due to smoke and other airborne particles.

To counter this level of risk, a 'network' of secure refuge chambers and changeover stations deployed strategically throughout an underground coal mine, is now being proposed in this document.

7.15.1.1 RISK STATEMENT

All mines to which this Code of Practice applies must be able to demonstrate that their emergency plans provide for the hazards associated with irrespirable atmospheres (refer to Nature of the Hazard), by installing suitable underground refuge chambers, and that these refuge chambers be effectively managed and maintained.

Effective risk management procedure is essential in preventing injuries and fatalities, and should abide by the following key principles:

- First: Identifying all potential hazards
- Second: Assessing the resulting risk(s) associated
- Third: Implementation of both preventative and responsive measures necessary to minimise the level of risk of harm and/or health to personnel.

7.15.1.2 NATURE OF THE HAZARD

The serious potential hazards associated with underground coal mining are well known to the industry. These include fires and explosions (resulting in extreme temperatures, smoke and other airborne particles), flooding, fall of ground, and a build up in noxious gases, particularly methane. All of which can lead to irrespirable and explosive atmospheres occurring.

Such hazards can block escape routes and leave personnel injured or simply overwhelmed – limiting or preventing their ability to safely evacuate the mine.

Explosions are a particularly prevalent safety risk in underground coal mining. Methane released from the coal seam and surrounding rock strata during the process of mining can present a high risk of explosion at concentrations in air of between 5-15%. Refer to appendix 12.

The majority of prior incidents resulting in injury and/or fatalities in the coal industry (globally) have been caused by the following: (refer Appendix 2 for direct reference case studies)

- Methane release
- Spontaneous combustion; resulting in explosion and/or fire
- Ignition sources; resulting in explosion and/or fire

Furthermore, the widespread use of diesel-powered and Intrinsically-Safe rated (IS) electrical equipment in underground coal mines has led to a growing inventory of combustible materials present. 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.

In the event of an underground hazard in which the atmosphere becomes irrespirable, there is an immediate need to secure a safe and reliable supply of breathable air.
For this reason, most underground mine workers are supplied 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 (an irrespirable atmosphere) to a position of safety outside the mine, or, to a predetermined place of safe-refuge underground (if one has been provided).

Typically, SCSR's only provide 30 minutes of breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed, with no impediments (refer appendix 11). With many underground networks extending over a number of kilometres, exiting the mine during an emergency situation (if indeed

possible) could prove to be a long and difficult journey, particularly for any personnel who have sustained injury and for those who may be assisting them. The need for a changeover of breathing apparatus whilst exiting the mine during an emergency situation is therefore a distinct possibility. Also, this changeover of the SCSR may be required within a non-secure (irrespirable) environment.

During an emergency situation personnel are also more likely to be anxious, breathing more heavily and therefore consuming more oxygen. Added to this would be levels of disorientation, shock, as well as a potential lack of visibility due to smoke and other airborne particles.

Taking into account all of the above, a change over of breathing apparatus, within a non-secure (irrespirable) environment, carries the real risk of inadvertently inhaling potentially life-threatening toxins.

To counter this level of risk, a 'network' of changeover stations and refuge chambers deployed strategically throughout an underground coal mine, is now being proposed.

Emergency changeover stations are designed to provide a short-term safety option where personnel can changeover breathing apparatus, communicate with the surface, and rest temporarily (if required) before continuing to plan their exit from the mine.

7.15.2 DEFINITIONS

7.15.2.1 CHANGEOVER STATION DEFINITION

A portable, self-contained structure designed to facilitate self-escape from an underground mine during an emergency situation: Providing an internally safe and secure breathable atmosphere stocked with SCSR's (Self Contained Self Rescuers) and/or a CABA (Compressed Air Breathing Apparatus) 'quick-fill' station. Inside a changeover station, breathing apparatus can be changed over in safety while personnel compose themselves, rest temporarily (if required), apply first aid (if required), make contact with the surface, and continue to plan their escape.

As a basic requirement, a change-over-station is therefore required to be blast proof (both primary and secondary) and fire resistant, with separate entry/exit air-lock flushing compartments leading to a positively pressured and sealed internal main chamber area stocked with multiple SCSR's and/or other forms of breathing apparatus.

Depending on the size of the mine, the number of active workplaces and the number of personnel underground at any one time, multiple change-over-stations may be deployed throughout the mine to create a 'network' accessible to all personnel.

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7.15.3 CHANGEOVER STATION DESIGN REQUIREMENTS

This sections aims to give guidance on the conceptual and detailed design and operation of a changeover station.

7.15.3.1 ATMOSPHERE

A changeover station is to provide a safe respirable atmosphere independent of external mine conditions.
In basic terms, human breathing consumes oxygen and expels carbon dioxide, carbon monoxide, water vapor and heat. Therefore a life support system is required within changeover stations to replace the oxygen consumed and remove exhausted carbon dioxide, carbon monoxide, moisture and heat to maintain the atmosphere within acceptable limits.

7.15.3.1.1 PRIMARY LIFE SUPPORT

7.15.3.1.1.1 EXTERNAL COMPRESSED AIR

Changeover stations should be fitted with an external compressed air supply as its primary means of life-support. In the event that the mine air supply continues to operate during an emergency it will provide indefinite life support by continually renewing the chamber internal atmosphere. The

external air supply should be sufficient to provide a minimum of 0.09m^3/min per person and compliant to Australian Standard AS NZS 1716:2003 Respiratory Protective Devices.
The acceptable air supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table.

Table 1 - Standards for acceptable air supply requirements

Air Supply Requirements	***Relevant Standard***
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 external atmosphere.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
A reliable source of respirable air must be supplied to the bay so as to ensure proper flushing and create a positive pressure. Where compressed air is used an arrangement for silencing must be made.	Directive B5 – Department of Mineral and Energy Affairs – South Africa

Following an emergency event such as rock fall, fire etc. It is possible for the external compressed air supply to be lost and therefore a secondary life support means in addition should be provided within the changeover station.

7.15.3.1.1.2 SECONDARY LIFE SUPPORT

7.15.3.1.1.2.1 OXYGEN SUPPLY

Oxygen is a key requirement for cellular activity and therefore the absence of oxygen for relatively short periods of time will result in death. Humans within an enclosed environment consume oxygen and if not replaced would result in an irrespirable atmosphere. Additionally, high oxygen levels can result in oxygen toxicity causing disorientation, breathing problems and other medical conditions.
The environment within a changeover station should therefore be maintained with an oxygen content between acceptable limits. The acceptable range according to Australian standard AS2865-1995 Safe Working in Confined Spaces is between 19.5% and 23.5%
The acceptable oxygen limits for a breathable environment are defined in various international standards, examples of which are listed in the below table

Table 2 - Standards for allowable oxygen level

Minimum Oxygen Content (% by volume)	***Maximum Oxygen Content (% by volume)***	***Relevant Standard***
19.5%	23.5%	AS 2865 – 1995
19%	23%	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
18.5%	23.0%	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
18.5%	23.0%	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
19.5%		West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

In the event of external air supply being lost a secondary oxygen supply (compressed medical grade oxygen cylinders) should be installed to provide a minimum of 0.5L per person per minute for the intended occupancy and entrapment duration of the changeover station.
The acceptable oxygen supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table

Table 3 – Acceptable Oxygen Supply Requirements

Oxygen Supply Requirements	***Relevant Standard***
The refuge chamber must be able to maintain an atmospheric concentration of: *Oxygen supply at a minimum of 33.7 Litres per person per hour.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
There is a risk that the air supply will be severed and, consequently, an independent means of supply must be	Department of Industry and Resources, 2005 Refuge Chambers in Underground metalliferous mines – guideline: Safety

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.	and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge chamber should equipped with self-prepared oxygen supply system to ensure that the oxygen supply per person within the nominal protection time is not lower than 0.5L/min. It should also meet the following requirements: *(1) Compressed oxygen supply mode is the priority. Chemical oxygen should not be used as the main oxygen supply mode.* *(2) The oxygen level should be no lower than 99.8%, and meets the GB8982*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
The minimum Oxygen storage capacity of a refuge shall be sufficient to: Provide 37.37L/hour per occupant for the specified occupancy duration of the refuge	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.3.1.1.3 CARBON DIOXIDE REMOVAL

Carbon dioxide is being produced continuously by the cells of our body. The inability to expel this gas or an environment with high concentrations of carbon dioxide leads to carbon dioxide poisoning. Breathing air with more than 30% CO2 can quickly induce unconsciousness and cause death

CO2 which is exhaled by chamber occupants must be removed by either constant flushing of the chamber with fresh air or by the recirculation of the chamber gas through a CO2 absorbent (scrubber).

A carbon dioxide scrubber must be provided within the changeover station to maintain levels within acceptable limits if the external compressed air supply is lost.

The acceptable carbon dioxide removal requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table.

Table 4 – Acceptable Carbon dioxide removal Requirements

Carbon Dioxide Removal Requirements	***Relevant Standard***
A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide (CO2) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess CO2 and CO can be removed.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The refuge chamber must be able to supply carbon dioxide removal system that can remove 33.7 litres and hour per	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries.

person.	New South Wales Government Gazette No. 67
"Carbon dioxide removal systems or atmospheric renewal systems for normal operation shall have the capacity to maintain the partial pressure of carbon dioxide below 0.005 bar continuously based on a production rate of 0.05 Nm^3 per hour per diver" (refer sec 4, 602) The system shall be designed so as to minimise the build up of carbon dioxide. Dead space volume should be as low as possible. The partial pressure of carbon dioxide (ppCO2) shall be limited to 1 Pa. (Sec 4, H1003)	Offshore Standard DNV-OS-E402
*The Refuge Chamber should be equipped with effective air purification system and temperature and humidity regulating system, with the facility to remove harmful gas. The CO2 processing capacity is no less than 0.5l/min*per man;*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

The carbon dioxide (CO2) removal capacity of the scrubber should be sufficient to remove no less than 24 litres/hour per person for the entrapment duration.
The maximum allowable CO2 level within the changeover station is 1% (or 10000ppm)
Independent testing completed has verified the build-up of CO2 within a refuge chamber and therefore confirms the need for a CO2 scrubbing system. Refer to appendix 3, 4 and 5
Carbon dioxide is a colorless, odorless gas usually does not pose a direct hazard to life because it typically becomes diluted to low concentrations very quickly. But in certain circumstances, CO2 may become concentrated at levels lethal to people,
CO2 which is exhaled by changeover station occupants must be removed by constant flushing of the chamber with fresh air or by the recirculation of the gas through a CO2 absorbent (scrubber). If either of these mechanisms is inadequate, the occupants can develop CO2 toxicity by re-breathing their own exhaled CO2.
A rapid accumulation of CO2 may cause unconsciousness before any symptoms are experienced.
A slower build up causes a variety of symptoms, including:

- Shortness of breath, air hunger
- Flushing of the face and sweating
- Light headedness, jerks tremors or convulsions
- Impaired vision
- Head ache

The acceptable exposure limits for carbon dioxide are defined in various international standards, examples of which are listed in the below table.

Table 4 - Standards for allowable carbon dioxide exposure levels

Exposure Limit		*Relevant Standard*
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
5000ppm	30,000ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment [NOHSC:1003(1995]
5000ppm	15,000ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
5000ppm	30,000ppm	United States Department of Labor – Occupational Health and Safety Administration
5000ppm	30,000ppm	National Institute of Occupational Safety and Health - USA
5000ppm	30,000ppm	American conference of Governmental Industrial Hygienists
5000ppm	-	"Grenzwerte am Arbeitsplatz" published by the Swiss National Insurance Fund (SUVA),
5000ppm	-	Japanese Journal of Occupational Health
5000ppm	-	Arbejdstilsynet (Central Labour Inspectorate) Norway

7.15.3.1.1.4 CARBON MONOXIDE REMOVAL

Carbon monoxide is an asphyxiant and is endogenously produced in humans at varying levels depending on different health factors (i.e. smokers, obese, hypertension, anemia, age) Refer to appendix 10

Inhalation of carbon monoxide causes cellular hypoxia by preventing blood from carrying sufficient oxygen. Carbon monoxide combines reversibly with hemoglobin to form carboxyhaemoglobin.

A carboxyhaemoglobin level of 0.4 to 0.7 percent is normally present in the blood of adults. In cigarette / cigar smokers, the range is 4 to 20 percent. Carboxyhaemaglobin level is dependent mainly on the following:

- Concentration of CO in the air
- Duration of exposure
- Ventilation rate
- Pre-inhalation carboxyhaemaglobin level

Carbon monoxide exposure exerts its main toxic effect via its ability to interfere with organs that have a high metabolic demand for oxygen. High atmospheric concentrations leading to

carboxyhaemaglobin levels of 50 – 60 percent are likely to lead to unconsciousness and convulsions. Collapse may occur very quickly. A carboxyhaemaglobin level of 70 – 80 percent is probably incompatible with life. Refer to appendix 7 and 8.

Carbon monoxide removal systems or atmospheric renewal systems shall be provided within the changeover station to maintain levels below the maximum exposure limit of 30ppm. Refer to appendix 8.

The acceptable carbon monoxide removal requirements are defined in various international standards, examples of which are listed in the below table.

Table 5 – Acceptable Carbon monoxide removal Rrequirements

Carbon Monoxide Removal Requirements	***Relevant Standard***
A CO Scrubber system that removes any harmful CO that may accumulate in the chamber, from sources such as – *People within the chamber* *Systems within the chamber; and* *People entering or exiting the chamber when the external environmental concentration of CO is at least 400ppm*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide (CO2) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess CO2 and CO can be removed.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chambers built for Chinese Coal Mines be equipped with an effective air purification system with the facility to remove CO. The air purification system must guarantee to decrease the CO intensity from 0.04% to below 0.0024% within 20 minutes.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

The acceptable exposure limits for carbon monoxide are defined in various international standards, examples of which are listed in the below table.

Table 6 - Standards for allowable carbon monoxide exposure levels

Exposure Limit		***Relevant Standard***
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
30ppm	200ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment

		[NOHSC:1003(1995]
30ppm	200ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
35ppm	200ppm	National Institute of Occupational Safety and Health - USA
50ppm	-	United States Department of Labor – Occupational Health and Safety Administration

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied refuge/changeover station. Results indicated a steady increase in carbon monoxide concentration within the chamber. Refer to appendix 4.
Further independent testing was completed by ECS Stack Pty Ltd. During these tests the CO levels within the chamber displayed a steady increase. Refer to appendix 5 and 6.
The Safety in Mines Research Advisory Committee (SIMRAC) found in their assessment of refuge bay designs in collieries that without ventilation in a refuge bay, due to contamination from door openings and leaking to the inside of the bay, carbon monoxide could reach the threshold limit value (TLV) within 8.5 hours. They also found that where workers are to stay for longer periods there must be a method to flush out the air or create a positive pressure inside the bay. The use of oxygen may not be sufficient to ensure that the level of CO and CO2 caused by exhaled breath does not reach dangerous limits. Refer to appendix 9.

7.15.3.1.1.5 COOLING AND DEHUMIDIFYING

The healthy human body maintains its internal temperature around 37°C. Variations, usually of less than 1°C, occur with the time of the day, level of physical activity or emotional state. A change of body temperature exceeding 1°C occurs only during illness or when environmental conditions surpass the body's ability to cope with extreme temperatures.

As the environment warms-up, the body tends to warm-up as well. The body's internal "thermostat" maintains a constant inner body temperature by pumping more blood to the skin and by increasing sweat production. In this way, the body increases the rate of heat loss to balance the heat burden created by the environment. In a very hot environment, the rate of "heat gain" exceeds the rate of "heat loss" and the body temperature begins to rise. A rise in the body temperature results in heat illnesses.

When a worker is subject to extreme conditions over a period of time, heat disorders and health effects will be experienced. Refer to appendix 1.

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied refuge/changeover station. The main purpose of this test was to determine the requirement for cooling in an occupied and sealed environment without air conditioning. Testing was stopped after two hours due to the heat within the chamber reaching 60°C. Refer to appendix 4.
The method of computation and interpretation of thermal balance is described in ISO 7933 International Standard – Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Heat Stress using Calculation of the Predicted Heat Strain. Refer appendix 14.
MineARC recommends that a cooling capacity of 117 watts per person be maintained.
The acceptable cooling requirements for underground refuges/changeover stations are defined in various international standards, examples of which are listed in the below table.

Table 7 - Standards for acceptable cooling requirements

Cooling Requirements	***Relevant Standard***

The refuge chamber must be provided with the following requirements: *Maintain an apparent temperature less than 35 degrees Celsius, taking into account –* *All internal heat loads (such a people, lighting, self rescuers, heat generated by scrubbing systems or other life support systems)* *External environmental conditions* *A minimum metabolic heat input of 117 watts per person; and* *Minimum humidity of 1.5 litres of water per day per person.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
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. Refridgerative 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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge Chamber should be equipped with effective air purification system and temperature and humidity regulating system. Within the nominal protection time, the internal oxygen, harmful gas intensity and apparent temperature should be ≤35%	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training
Apparent temperature in the fully occupied refuge chamber must not exceed 95 degrees Fahrenheit	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.3.1.1.6 ATMOSPHERIC MONITORING

The changeover station must be equipped with an internal and external environmental monitoring system. In case of emergency, it must be able to monitor the O2, CO2, CO, CH4 (methane), temperature and humidity.

Environmental monitoring shall be provided within the changeover station to ensure that levels inside the changeover station are below the maximum exposure limit.
The acceptable environmental monitoring requirements for underground refuges/ changeover stations are defined in various international standards, examples of which are listed in the below table.
Table 8 - Standards for acceptable environmental monitoring in refuge chambers.

Environmental monitoring Requirements	***Relevant Standard***
Parameters that could jeopardize the safety of divers, and or violate the integrity of a diving system, shall be monitored and evaluated with a frequency that enables remedial actions to be carried out before personal harm is done or the system is damaged. *Oxygen analyzing systems shall have an accuracy of at least +/-0.015 bar partial pressure oxygen.* *Carbon dioxide analyzing systems shall have an accuracy of +/-0.01 bar partial pressure.*	Offshore Standard DNV-OS-E402
The refuge chamber should be equipped with Independent internal and external environment parameter monitoring system. In case of emergency, it can monitor the O2, CO in the airlock, the O2, CH4, CO2, CO, temperature, humidity and pressure difference in the life support compartment, and the O2, CH4, CO2, CO outside the chamber. *When using portable sensor for testing the outside environment parameter, reliable safety measures should be applied. When making monitoring with gas sampling, the gas sample should not be released inside the chamber.* *02 analysis sensor or test device must have an accuracy of 0.1%* *CO2 analyser must have accuracy within 0.1%* *CO analyser must have accuracy within 2%*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Air monitoring equipment with the ability to monitor CO2, CO, O2, CH4 inside and outside the refuge.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health

	Administration
Provide the ability to monitor carbon monoxide and oxygen inside and outside the shelter/chamber;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.4 CAPACITY

Changeover station manufacturers should specify the life supporting capacity of each station including number of occupants and duration of changeover.

7.15.4.1.1 OCCUPANCY

The primary function of an underground changeover station is to facilitate self-escape from the mine by providing a safe and secure area for personnel to changeover breathing apparatus in the event of an emergency. The changeover station design should recognise the reasonable amount of time taken per person to changeover breathing apparatus, as well as the total number of occupants passing through the changeover station at any one time. The total number of potential occupants should take into account supervisors, surveyors, geologists and service technicians that may also need to use the facility. The number of such people in the workings from time to time can require:

- Provision for a changeover station capacity more than double that determined from the size of the locally operating crew alone; and
- Provision for breathing apparatus capacity within the changeover stations 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

The entry of additional persons beyond the rated capacity will reduce the performance of the changeover station.

7.15.4.1.2 DURATION

The nominal duration means the minimum number of hours that a changeover station meets the performance criteria while occupied to its rated capacity and at maximum operating conditions, e.g. ambient temperature.
The changeover station must be rated by the manufacturer for compliance with design and performance standards and specify its maximum operational range.
The changeover station supplies the maximum number of occupants as specified by the manufacturer with breathable air and cooling for each occupant for a minimum specified duration in stand alone mode (without external air or power supply). This duration is to be determined by the mine's ERP.
Changeover stations are intended to supply life support for a small number of personnel for short periods at a time, thereby facilitating the walk- through operational objective. E.g. a 12 hour net duration changeover station provides 48 changeover periods based on 15 minutes per changeover. MineARC recommends a minimum net duration of 12 hours.
The acceptable duration requirements for underground refuges/ changeover stations are defined in various international standards, examples of which are listed in the below table.

Table 9 - Standards for duration requirements

Duration Requirements	*Relevant Standard*
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The nominal protection time of refuge chamber isn't lower than 96h, with the safety factor more than 1.1 times.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
The breathable air sustains each person for 96 hours.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
Provide a minimum of 48 hours life support (air, water, emergency medical supplies, and food) for the maximum number of miners reasonably expected on the working section;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.5 ANCILLARY EQUIPMENT

7.15.5.1 FIRST AID KIT

A comprehensive first aid kit is an obvious and necessary provision in a changeover station. 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.

7.15.6 DESIGN AND CONSTRUCTION

7.15.6.1.1 STRUCTURAL INTEGRITY

Changeover stations are to provide a safe environment for mine workers in the event of an underground emergency and to facilitate self-escape from the mine. It therefore follows that the changeover station itself should be sufficiently robust to remain operational following such an incident.

Explosions are a major risk in coal mines and any changeover station that is to be deployed must be built to withstand an explosion.

Explosions occur by the oxidisation of coal particles, methane or other combustible materials within a coal mine which results in a rapid expansion of gas causing an explosive pressure pulse to travel within the mine.

The matter is exacerbated when a coal dust explosion occurs. Firstly the charge mass is now increased due to the coal dust acting as fuel, and secondly the explosive is actually caused by the mechanical action of gases (the coal dust is being lifted into the air). Instead of the explosive being depleted during the chemical reaction, it is being supplemented as the explosion progresses, which leads to the phenomena of the peak pressure actually increasing with the distance that the explosion travels. This will continue until the fuel or oxygen is depleted, after which the explosion will reduce. Refer to appendix 9.

Another effect of an explosion, is a resultant negative pressure. This is almost instantaneously following an explosive blast and is caused by the resultant velocity and momentum of expanded gases. The negative pressure is usually significantly smaller and longer in duration than the positive phase but should still be considered in the design of a refuge chamber. An example explosive pressure pulse is shown below.

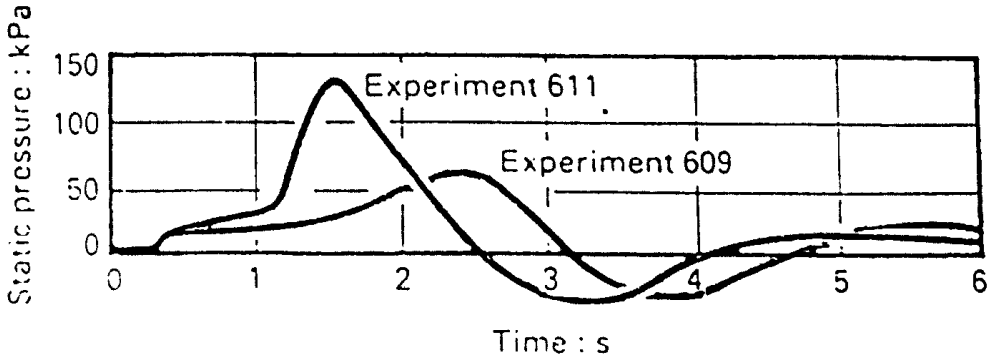

Figure 1 – Explosion pressure pulse

Changeover stations to be deployed in a coal mine should at a minimum be able to withstand a minimum of 15psi overpressure as explosions with greater maximum pressure can result in fatalities. Refer appendix 9.

Critical Event[42]	Related Max Pressure psi (kPa)
Felt as a sudden blow	2 (14)
Eardrum failure	5 (35)
Person knocked off feet	6 (42)
Lung damage threshold	15 (105)
Lethality:	
threshold	30-42 (210-294)
50 %	42-57 (294-399)
95-100	50-90 (350-630)

Figure 2 – Effect of pressure critical events.

Pressure rating within the mine should be risk assessed and higher rated changeover stations should be considered.

Changeover stations must be able to withstand explosive over pressure but should also be designed to withstand the resultant negative pressure.

MineARC recommends that changeover stations for coal mines be designed to withstand 25% negative pressure following a positive pressure blast (3.75 PSI)

The acceptable positive pressure limits are defined in various international standards, examples of which are listed in the below table.

Table 10 - Standards for overpressure requirements in refuges/changeover stations

Requirements	***Standard***
Refuge chamber should have enough strength. The explosion proof capability is no less than 0.3MPa, that is, under the condition that the operation time is no less than 300ms, the maximum peak overpressure of flow field pressure load that refuge chamber can withstand is no less than 0.3MPa.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Be capable of surviving an initial event with a peak overpressure of 15 psi for 3 seconds	WV
Be designed and made to withstand 15 pounds per square inch overpressure for 0.2 seconds prior to deployment.	MSHA Final Rule
Refuge bays must be of robust construction and where there is a high risk of explosion it must be able to withstand the effects of such an explosion	Directive B5 – Department of Mineeal and Energy Affairs – South Africa

7.15.6.1.2 DOORS AND HATCHES

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

The sealing of a changeover station 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 station is a worthwhile precaution.

A closely fitting door, fully sealed when closed, is the normal means of access to a changeover station. 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 station 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 atmosphere.

7.15.6.1.3 EMERGENCY EXIT

A changeover station is to be fitted with a minimum of two means of egress. Due to the risk of a main access door being blocked by rock fall, vehicle or other obstacle. A minimum of one emergency exit should be provided with an inwards opening door.
The design of the changeover station must provide for:

- A primary means of egress that is capable of allowing a stretcher to enter and to exit.
- An emergency exit with a door that opens inwards and is located as far as practical from the main entrance.

The acceptable secondary means of egress for underground refuges / changeover stations are defined in various international standards, examples of which are listed in the below table.

Table 11 - Standards for secondary means of egress

Requirements	***Standard***
The design of the refuge chamber must provide for *A primary means of egress that is capable of allowing a stretcher to enter and exit.* *A second emergency exit incase the primary exit has been blocked.* *The primary means of egress must not allow harmful amounts of gases to enter the refuge chamber*	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resounces Western Australia, 32 pp.
The refuge chamber should be provided with emergency escape hatch, to ensure the refuge people's escape when the entry door cannot be opened normally. The dimension of the emergency escape hatch is between 0.25 – 0.30m2, and is not recommended to be on the same side as the entry door.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide a means for entry and exit that maintains the integrity of the internal atmosphere;	WV

7.15.6.1.4 AIRLOCK

An airlock, or airlocks, are required to prevent the ingress of toxlc gases into the occupied space of the changeover station.
Changeover stations featuring an entry and exit door should be fitted with an airlock system on both doors. An airlock system should incorporate a double-door design.

When the airlock is flushed it must reduce or remove contaminants to within acceptable levels as defined in section 7.15.3 Atmosphere.

7.15.6.1.5 PRESSURE EQUALISATION

The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200Pa greater than the outside environment. This will prevent the ingress of toxic gases into the changeover station. Over pressure protection should also be installed.
The acceptable level of pressure equalisation for underground refuges / changeover stations are defined in various international standards, examples of which are listed in the below table

Table 12 - Standards for secondary means of egress

Requirements	***Standard***
Maintain a positive pressure nominally 1.75kPa greater than the outside environment, over-pressurisation protection ie to be able to safely discharge excess air from the refuge chamber	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resounces Western Australia, 32 pp.
Refuge chamber should have enough air tightness. At the pressure of 500Pa, pressure relief rate is no larger than 350Pa/h. The internal air pressure should be kept 100 – 500Pa higher than the outside air pressure, and is adjustable according to actual situation.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Include an airlock that creates a barrier and isolates the interior space from the mine atmosphere, except for a refuge alternative capable of maintaining adequate positive	MSHA Final Rule

pressure.	
Refuge bays must be air leak proof, sealed in such a way so as to ensure a positive pressure when in use	Directive B5 – Department of Mineeal and Energy Affairs – South Africa
A pressure control system is to be used to prevent the internal pressure at any point in the diving system rising to excessive levels, or falling below prescribed levels. The pressure control system comprises the pressure regulating systems, pressure safety systems and associated instrumentation and alarm systems.	Offshore Standard DNV-OS-E402

7.15.6.1.6 VIEW PORT

The provision of a window for a changeover station is a useful and simple feature. It enables visual communication between the inside and outside, and can help lessen the feeling of being enclosed. All external windows should be explosion rated to 15psi and its retaining structure must be capable of withstanding external overpressure, particularly that caused by blasting. It is recommended that view ports be installed in the airlock as well as the main chamber to verify that the main chamber or airlock are in use.

7.15.6.1.7 PAINTED SURFACES

The interiors of changeover stations 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 over a period of time can be detrimental to health. Consequently, it is advisable to use a water-based epoxy paint, which on curing does not emit contaminants.

7.15.6.1.8 EXCLUSION OF FLAMMABLE MATERIALS

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

7.15.6.1.9 ELECTRICAL EQUIPMENT

All electrical equipment associated with the changeover station must be intrinsically safe in accordance with AS/NZS 60079 – Intrinsically Safe (i).

7.15.6.1.9.1 STROBE LIGHT

Darkness is inevitable in an underground environment and can be increased to a level of virtual impenetrability by smoke from a fire. This can make the changeover station difficult to locate by people seeking safety. An intrinsically safe high-intensity strobe light fitted close to the door(s) of the station can make it easier to find in smoky conditions.

7.15.6.1.9.2 INTERNAL LIGHTING

Chemical light sticks or intrinsically safe cap lamps can provide adequate lighting for occupants within changeover station.

7.15.6.1.10 SEATING

Adequate seating is to be supplied for the maximum number of occupants. Allocated seating space is to be 600mm x 600mm including leg space per occupant.

7.15.7 LOCATION

A changeover station is designed to protect the lives of the underground workforce and is used as a safe area for evacuation in an emergency. Its correct location and capacity is critical to the success of the designed system. Although the positioning of a changeover station is strongly governed by its accessibility for people, its selected location is crucial for its ability to function correctly in the event of an emergency.

7.15.7.1.1 DISTANCE FROM THE WORKPLACE

MineARC Systems recommends that changeover stations 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 changeover station be based on how far a person, in a reasonable state of physical fitness, can travel at a moderate walking pace, using 50% of the nominal duration of the SCSR. If it is assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety.
This distance should be regarded as an absolute maximum because:

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

It should be noted that crawling is necessarily slower than moderate walking, and should be allowed for where applicable.

7.15.7.1.1.1 NOMINAL DURATION OF SCSR's

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 attempts to build a realistic and practical safety margin into the duration of SCSRs. See appendix 11.

7.15.7.1.2 SAFETY OF LOCATION

7.15.7.1.3 EXPOSURE TO HAZARDS

Although the positioning of a changeover station is strongly governed by its accessibility for people in need of its protection, any potential susceptibility of its location to the hazards of rock fall, flooding, fire, explosion or damage from mine vehicles should be considered.
The placing of a changeover station 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.

7.15.7.1.4 GROUND CONDITIONS

While it is recognised that it may be impossible to locate a changeover station excavation in an area free from normal rock mass 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 changeover station, its external service equipment, or restrict access to or from the station.
The ground support installed in the vicinity of a changeover station 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 changeover stations. 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 changeover station and its associated equipment, poor ground conditions can introduce a hazard to personnel servicing the station on a routine basis, and people attempting to enter the facility for any other purpose.

7.15.7.1.5 WATER

A changeover station should not be placed in a location where water can accumulate in sufficient quantities to pose a risk to workers. Many stations 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 changeover station 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.

7.15.8 CERTIFICATION AND MAINTENANCE

7.15.8.1.1 MAINTENANCE

For a changeover station to fulfill 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 and due to the highly corrosive and abrasive atmosphere, changeover

stations should be inspected regularly and basic tests carried out (minimum four monthly) to ensure full functionality or as per the manufacturer's recommendations.
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 station and advised of the alternative arrangements in the event of an emergency.
Responsibility for the ongoing integrity of a mine's changeover station or stations should be clearly established by site management. Any repair or maintenance work will devolve to the engineering personnel, who should have access to the necessary information and equipment to undertake their duties.

7.15.8.1.2 COMMISSIONING

A commissioning test should be carried out when a changeover station 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 changeover station should be fully and regularly audited. This should take place at four month intervals.
Operational experience indicates that the functionality of a changeover station is most vulnerable during relocation. A full commissioning check should be undertaken as soon as possible after each move.

7.15.8.1.3 CERTIFICATION

MineARC Systems recommends that manufacturers have their changeover station designs certified and approved by the relevant regulatory authority before they may be deployed in underground mines. This is to ensure that changeover stations being used within Australian mines can meet the specified performance criteria outlined in the legislation. Manned testing should be completed to verify the life support capacity of the changeover station for a minimum of 1/3 of its rated duration, in stand alone mode. All tests should be verified by an independent body to the satisfaction of the regulatory authority.

7.15.9 SUMMARY

During an emergency situation, the first priority for all underground personnel should be to exit the coal mine via predetermined egresses and escape routes. However, emergency situations have occurred in the past, and remain likely to occur, in which personnel have become cut off and/or found it difficult to exit the mine.

Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas (such as methane) can block escape routes and leave personnel injured or simply overwhelmed.

Typically, SCSR's only provide 30 minutes breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed with no impediments. With many underground networks extending over a number of kilometers, exiting the mine during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury, and for those who may be assisting them.

The need for a changeover of breathing apparatus whilst exiting the mine during an emergency situation is therefore a distinct possibility. Also, this changeover of the SCSR may be required within a non-secure (irrespirable) environment, which carries the real risk of inadvertently inhaling potentially life-threatening toxins.

To counter this level of risk, it has been proposed here in this document that emergency changeover stations form an integral part of an underground coal mine's wider Emergency Response Plan (ERP). Changeover stations should be designed to provide a safe and secure 'go-to' area for personnel to changeover breathing apparatus in the event of an emergency.

A changeover station is a portable, self-contained structure designed to facilitate self-escape from an underground mine during an emergency situation: Providing an internally safe and secure breathable atmosphere stocked with SCSR's (Self Contained Self Rescuers) and/or a CABA (Compressed Air Breathing Apparatus) 'quick-fill' station.

A suitable changeover station therefore has the following design requirements:

Breathable Air Supply:

Changeover stations should be fitted with an external compressed air supply as its primary means of life-support. The external air supply should be sufficient to provide a minimum of 0.09m^3/min per person

The environment within a changeover station should therefore be maintained with oxygen content between acceptable limits. The acceptable range is between 19.5% and 23.5%

In the event of external air supply being lost a secondary oxygen supply should be installed to provide a minimum of 0.5L per person per minute.

Carbon dioxide removal systems shall be provided within the changeover station to maintain levels below 1%.

Carbon monoxide removal systems shall also be provided within the changeover station to maintain levels below 30ppm.

Cooling:

The acceptable cooling requirements for underground changeover stations are defined in various international standards. All changeover station designs must take into account all internal heat loads such as people, lighting, heat generated by scrubbing systems, external environmental conditions, a minimum metabolic heat input of 117 watts per person; and minimum humidity of 1.5 litres of water per day per person.

Atmospheric Monitoring:

The changeover station must be equipped with independent internal and external environment monitoring systems. In case of emergency, it must be able to monitor the O2, CO2, CO, CH4 in the station.

Capacity and Safe Entrapment Duration:
The nominal duration means the minimum number of hours that a changeover station meets the performance criteria while occupied to its rated capacity and at maximum operating conditions e.g ambient temperature.
The changeover station must be rated by the manufacturer for compliance with design and performance standards and specify its maximum operational range.
The changeover station supplies the maximum number of occupants as specified by the manufacturer with breathable air and cooling for each occupant for a minimum specified duration in standalone mode (without external air or power supply). This duration is to be determined by the mine's ERP.
Changeover stations are intended to supply life support for a small number of personnel for short periods at a time, thereby facilitating the walk- through operational objective. E.g. a 12 hour net duration changeover station provides 48 changeover periods based on 15 minutes per changeover. MineARC recommends a minimum net duration of 12 hours.
.
Structural Integrity:
The construction of a changeover station should allow for the circumstances in which it will be used. The station and its equipment mountings must be very robust
When in use, a changeover station must remain totally sealed off from the surrounding atmosphere. All access doors must fit properly and seals must always be maintained and monitored in good condition.
The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200 Pa greater than the outside environment. This will prevent the ingress of toxic gases into the station. Over pressure protection should also be installed.

Electrical equipment:
All electrical equipment associated with the changeover station must be intrinsically safe in accordance with AS/NZS 60079 – intrinsically safe (i)

Changeover Station Positioning:
Although the positioning of a changeover station is strongly governed by its accessibility for people, its selected location is crucial for its ability to function correctly in the event of an emergency. If it is assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety. This distance should be regarded as an absolute maximum.
Inspection and Maintenance:
For a changeover station to fulfill its primary purpose, it must be ready at all times for immediate, dependable use. This requires an effective and rigorous inspection and maintenance regime.
Certification:
MineARC Systems recommends that manufacturers have their changeover station designs certified by the relevant regulatory authority to ensure that products being used within Australian mines can meet the specified performance criteria.

APPENDIX 1 – HEAT DISORDERS AND HEALTH EFFECTS

When a worker is subject to extreme conditions over a period of time, the following heat disorders and health effects will be experienced. (United States Department of Labor Directive TED 01 – 00 – 015 OSHA Technical Manual Chapter III)

I. HEAT DISORDERS AND HEALTH EFFECTS.

A. **HEAT STROKE** occurs when the body's system of temperature regulation fails and body temperature rises to critical levels. This condition is caused by a combination of highly variable factors, and its occurrence is difficult to predict. Heat stroke is a medical emergency. The primary signs and symptoms of heat stroke are confusion; irrational behavior; loss of consciousness; convulsions; a lack of sweating (usually); hot, dry skin; and an abnormally high body temperature, e.g., a rectal temperature of 41°C (105.8°F). If body temperature is too high, it causes death. The elevated metabolic temperatures caused by a combination of work load and environmental heat load, both of which contribute to heat stroke, are also highly variable and difficult to predict.

If a worker shows signs of possible heat stroke, professional medical treatment should be obtained immediately. The worker should be placed in a shady area and the outer clothing should be removed. The worker's skin should be wetted and air movement around the worker should be increased to improve evaporative cooling until professional methods of cooling are initiated and the seriousness of the condition can

be assessed. Fluids should be replaced as soon as possible. The medical outcome of an episode of heat stroke depends on the victim's physical fitness and the timing and effectiveness of first aid treatment.

Regardless of the worker's protests, no employee suspected of being ill from heat stroke should be sent home or left unattended unless a physician has specifically approved such an order.

B. **HEAT EXHAUSTION**. The signs and symptoms of heat exhaustion are headache, nausea, vertigo, weakness, thirst, and giddiness. Fortunately, this condition responds readily to prompt treatment. Heat exhaustion should not be dismissed lightly, however, for several reasons. One is that the fainting associated with heat exhaustion can be dangerous because the victim may be operating machinery or controlling an operation that should not be left unattended; moreover, the victim may be injured when he or she faints. Also, the signs and symptoms seen in heat exhaustion are similar to those of heat stroke, a medical emergency.

Workers suffering from heat exhaustion should be removed from the hot environment and given fluid replacement. They should also be encouraged to get adequate rest.

C. **HEAT CRAMPS** are usually caused by performing hard physical labor in a hot environment. These cramps have been attributed to an electrolyte imbalance caused by sweating. It is important to understand that cramps can be caused by both too much and too little salt. Cramps appear to be caused by the lack of water replenishment. Because sweat is a hypotonic solution (±0.3% NaCl), excess salt can build up in the body if the water lost through sweating is not replaced. Thirst cannot be relied on as a guide to the need for water; instead, water must be taken every 15 to 20 minutes in hot environments.

Under extreme conditions, such as working for 6 to 8 hours in heavy protective gear, a loss of sodium may occur. Recent studies have shown that drinking commercially available carbohydrate-electrolyte replacement liquids is effective in minimizing physiological disturbances during recovery.

D. **HEAT COLLAPSE** ("Fainting"). In heat collapse, the brain does not receive enough oxygen because blood pools in the extremities. As a result, the exposed individual may lose consciousness. This reaction is similar to that of heat exhaustion and does not affect the body's heat balance. However, the onset of heat collapse is rapid and

unpredictable. To prevent heat collapse, the worker should gradually become acclimatized to the hot environment.

E. **HEAT RASHES** are the most common problem in hot work environments. Prickly heat is manifested as red papules and usually appears in areas where the clothing is restrictive. As sweating increases, these papules give rise to a prickling sensation. Prickly heat occurs in skin that is persistently wetted by unevaporated sweat, and heat rash papules may become infected if they are not treated. In most cases, heat rashes will disappear when the affected individual returns to a cool environment.

F. **HEAT FATIGUE**. A factor that predisposes an individual to heat fatigue is lack of acclimatization. The use of a program of acclimatization and training for work in hot environments is advisable. The signs and symptoms of heat fatigue include impaired performance of skilled sensorimotor, mental, or vigilance jobs. There is no treatment for heat fatigue except to remove the heat stress before a more serious heat-related condition develops.

APPENDIX 2 – MINE INCIDENTS

APPENDIX 3 – RESEARCH PAPER, INTEGRATION OF SELF AND AIDED RESUE

APPENDIX 4 TEST REPORT 18050 REFUGE CHAMBER THERMAL STUDY

APPENDIX 5 TEST REPORT R09289 MINEARC UNDERGROUND GAS TESTING

APPENDIX 6 TEST REPORT R08281 MINEARC UNDERGROUND ATMOSPHERE TESTING

APPENDIX 7 OCCUPATIONAL SAFETY AND HEALTH GUIDELINE FOR CARBON MONOXIDE

APPENDIX 8 EXPOSURE STANDARD DOCUMENTATION FOR CARBON MONOXIDE

APPENDIX 9 SIMRAC PROJECT REPORT COL 115 – ASSESSMENT OF REFUGE BAY DESIGNS IN COLLIERIES

APPENDIX 10 RESEARCH PAPER ENDOGENOUS CARBON MONOXIDE PRODUCTION IN MAN

APPENDIX 11 – REPORT INTO SELF AIDED RECUE

APPENDIX 12 – RESEARCH REPORT INTO EXPLOSIVITY

APPENDIX 13 – WESTERN AUSTRALIAN GUIDELINE FOR REFUGE CHAMBERS IN METALLIFEROUS MINES

APPENDIX 14 – ISO STANDARD – ASSESSMENT OF HEAT STRESS

FINAL coal chamber COP submission

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Public comments on Draft Code of Practice
EMERGENCY RESPONSE AT AUSTRALIAN MINES

INTRODUCTION

Established in 1999, MineARC Systems is now the global leader in the manufacture and supply of emergency refuge chambers to the underground mining, tunneling, nuclear and chemical processing industries.

Emergency refuge chambers form an integral part of an underground mine, tunnel, nuclear or chemical operation's wider Emergency Response Plan (ERP). Fires, explosions, rock-falls, flooding, and the release of smoke and other forms of toxic gas are the types of industrial incidents that occur all too frequently, (refer to appendix 2) despite the high levels of planning and safety precautions in place.

In these types of emergencies, when evacuation is no-longer safe or practical, emergency refuge chambers are designed to provide a safe and secure 'go-to' area for personnel to gather and await extraction. MineARC refuge chambers have been successfully used around the world in multiple mine and tunneling emergencies to save lives. Refer to appendix 2.

Inside a standard MineARC refuge chamber a number of vital life support systems combine to create a safe and secure ongoing environment for occupants, including; oxygen supply, carbon dioxide (CO_2) and carbon monoxide (CO) scrubbing, cooling and gas monitoring.

Today MineARC has offices and manufacturing facilities in Perth, Western Australia; Santiago, Chile; Fushun, China; Pretoria in South Africa and Dallas in the United States, as well as a strong distribution network worldwide. In all, MineARC manufactures refuge chambers for operations in over 30 countries world-wide.

All MineARC refuge chambers comply with the highest international industry regulations, standards and guidelines.

MineARC hard-rock refuge chambers comply in full with the West Australian Department of Mines & Petroleum (DMP) industry Guidelines. MineARC hard-rock refuge chambers are also European CE and Australian C-Tick certified and is ISO9001 certified.

MineARC Systems would like to submit the following comments and recommendations for:
Draft Code of Practice – 7.15 Refuge Procedures - EMERGENCY RESPONSE AT AUSTRALIAN MINES

7.15B REFUGE PROCEDURES FOR COAL MINES

7.15.10 BACKGROUND

During an emergency situation, the first priority for all underground personnel should be to exit the coal mine via predetermined egresses and escape routes. However, emergency situations have occurred in the past, and the potential remains, in which personnel have become cut off and/or left unable to exit the mine themselves.

Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas (such as methane) can block escape routes and leave personnel injured or simply overwhelmed. Examples of incidents that have occurred can be found in appendix 2 of this document.

In an emergency situation personnel will be required to don breathing apparatus (self contained self rescuers (SCSR)), as smoke and other noxious gases contaminate the air. Typically, SCSR's only provide 30 minutes breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed with no impediments (refer appendix 11). With many underground networks extending over a number of kilometres, exiting the mine during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury, and for those who may be assisting them.

The need for a changeover of breathing apparatus whilst exiting the mine during an emergency situation is therefore a distinct possibility. Further, this changeover may be required within a non-secure (irrespirable) environment. Personnel may also be suffering from disorientation, shock, and a potential lack of visibility due to smoke and other airborne particles.

To counter this level of risk, a 'network' of secure refuge chambers and changeover stations deployed strategically throughout an underground coal mine, is now being proposed.

7.15.10.1.1 RISK STATEMENT

All mines to which this Code of Practice applies must be able to demonstrate that their emergency plans provide for the hazards associated with irrespirable atmospheres (refer to Nature of the Hazard), by installing suitable underground refuge chambers, and that these refuge chambers be effectively managed and maintained.

Effective risk management procedure is essential in preventing injuries and fatalities, and should abide by the following key principles:

- First: Identifying all potential hazards
- Second: Assessing the resulting risk(s) associated
- Third: Implementation of both preventative and responsive measures necessary to minimise the level of risk of harm and/or health to personnel.

7.15.10.1.2 NATURE OF THE HAZARD

The serious potential hazards associated with underground coal mining are well known to the industry. These include fires and explosions (resulting in extreme temperatures, smoke and other airborne particles), flooding, fall of ground, and a build up in noxious gases, particularly methane. All of which can lead to irrespirable and explosive atmospheres occurring.

Such hazards can block escape routes and leave personnel injured or simply overwhelmed – limiting or preventing their ability to safely evacuate the mine.

Explosions are a particularly prevalent safety risk in underground coal mining. Methane released from the coal seam and surrounding rock strata during the process of mining can present a high risk of explosion at concentrations in air of between 5-15%. Refer to appendix 12

The majority of prior incidents resulting in injury and/or fatalities in the coal industry (globally) have been caused by the following: (refer Appendix 2 for direct reference case studies)

- Methane release
- Spontaneous combustion; resulting in explosion and/or Ignition sources; resulting in explosion and/or fire

Furthermore, the widespread use of diesel-powered and Intrinsically-Safe rated (IS) electrical equipment in underground coal mines has led to a growing inventory of combustible materials present. 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.

In the event of an underground hazard in which the atmosphere becomes irrespirable, there is an immediate need to secure a safe and reliable supply of breathable air.
For this reason, most underground mine workers are supplied 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 (an irrespirable atmosphere) to a position of safety outside the mine, or, to a predetermined place of safe-refuge underground (if one has been provided).

Typically, SCSR's only provide 30 minutes of breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed, with no impediments (refer appendix 11). With many underground networks extending over a number of kilometres, exiting the mine during an emergency situation (if indeed possible) could prove to be a long and difficult journey, particularly for any personnel who have sustained injury and for those who may be assisting them. The need for a changeover of breathing

apparatus whilst exiting the mine during an emergency situation is therefore a distinct possibility. Also, this changeover of the SCSR may be required within a non-secure (irrespirable) environment.

During an emergency situation personnel are also more likely to be anxious, breathing more heavily and therefore consuming more oxygen. Added to this would be levels of disorientation, shock, as well as a potential lack of visibility due to smoke and other airborne particles.

Taking into account all of the above, a changeover of breathing apparatus, within a non-secure environment, carries the real risk of inadvertently inhaling potentially life-threatening toxins.

To counter this level of risk, a 'network' of refuge chambers and changeover stations deployed strategically throughout an underground coal mine, is now being proposed.

Emergency refuge chambers are designed to provide a long-term safety option where personnel can gather and await extraction when escape is impossible – potentially for days. Additionally, refuge chambers can also be used to provide a safe and secure change-over-station where personnel changeover breathing apparatus before continuing to plan their exit from the mine, should they be able to exit the mine safely.

7.15.11 DEFINITIONS

7.15.11.1.1 REFUGE CHAMBER DEFINITION

A manufactured rigid vessel that is outfitted with supplies and equipment to sustain life for a period of time (potentially days) while mine workers wait for rescue. Mine workers take refuge in a chamber only when evacuating a mine is no longer safe, practical, or when escape is impossible (for example when a hazard has blocked designated escape routes and egresses).

As a basic requirement, a refuge chamber should therefore be blast proof (both primary and secondary) and fire resistant, with an entry air-lock flushing compartment leading to a positively pressurised and sealed internal main chamber area stocked with multiple SCSR's and/or other forms of breathing apparatus. The refuge chamber should also be fitted with back-up air supply, CO/CO2 scrubbing and cooling capabilities. All the above life support systems must be intrinsically safe. They must also be capable of operating 'stand-alone' for a nominal duration (dependent upon the mines ERP), i.e. without being connected to a mine's 'mains' supply of air/power.

Depending on the size of the mine, the number of active workplaces and the number of personnel underground at any one time, multiple refuge chambers may be required, and should be deployed throughout the mine to create a 'network', accessible to all personnel.

7.15.12 REFUGE CHAMBER DESIGN REQUIREMENTS

This sections aims to give guidance on the conceptual and detailed design and operation of a refuge chamber.

7.15.12.1 ATMOSPHERE

A refuge chamber is to provide a safe respirable atmosphere independent of external mine conditions.
In basic terms, human breathing consumes oxygen and expels carbon dioxide, carbon monoxide, water vapor and heat. Therefore a life support system is required within the refuge chamber to replace the oxygen consumed and remove exhausted carbon dioxide, carbon monoxide, moisture and heat to maintain the atmosphere within acceptable limits.

7.15.12.1.1 PRIMARY LIFE SUPPORT

7.15.12.1.1.1 EXTERNAL COMPRESSED AIR

Refuge chambers should be fitted with an external compressed air supply as its primary means of life-support. In the event that the external compressed air supply continues to operate during an emergency, it will provide indefinite life support by continually renewing the chamber internal atmosphere. The external air supply should be sufficient to provide a minimum of 0.09m^3/min per person and compliant to Australian Standard AS NZS 1716:2003 Respiratory Protective Devices.

The acceptable air supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table.

Table 1 - Standards for acceptable air supply requirements

Air Supply Requirements	***Relevant Standard***
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 external atmosphere.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
A reliable source of respirable air must be supplied to the bay so as to ensure proper flushing and create a positive pressure. Where compressed air is used an arrangement for silencing must be made.	Directive B5 – Department of Mineral and Energy Affairs – South Africa

Following an emergency event such as rock fall, fire etc. It is possible for the external compressed air supply to be lost and therefore a secondary life support means in addition should be provided within the chamber.

7.15.12.1.1.2 SECONDARY LIFE SUPPORT

7.15.12.1.1.2.1 OXYGEN SUPPLY

Oxygen is a key requirement for cellular activity and therefore the absence of oxygen for relatively short periods of time will result in death. Humans within an enclosed environment consume oxygen

and if not replaced would result in an irrespirable atmosphere. Additionally, high oxygen levels can result in oxygen toxicity causing disorientation, breathing problems and other medical conditions.
The environment within a refuge chamber should therefore be maintained with an oxygen content between acceptable limits. The acceptable range according to Australian Standard AS2865-1995 "Safe Working in Confined Spaces" is between 19.5% and 23.5%
The acceptable oxygen limits for a breathable environment are defined in various international standards, examples of which are listed in the below table.

Table 2 - Standards for allowable oxygen level

Minimum Oxygen Content (% by volume)	***Maximum Oxygen Content (% by volume)***	***Relevant Standard***
19.5%	23.5%	AS 2865 – 1995
19%	23%	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
18.5%	23.0%	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
18.5%	23.0%	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
19.5%		West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

In the event of external air supply being lost a secondary oxygen supply (compressed medical grade oxygen cylinders) should be installed to provide a minimum of 0.5L per person per minute for the intended occupancy and entrapment duration of the refuge chamber.
The provision of a third backup oxygen supply from oxygen candles is strongly recommended. Refer to appendix 13
The acceptable oxygen supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table.

Table 3 – Acceptable Oxygen Supply Requirements

Oxygen Supply Requirements	***Relevant Standard***
The refuge chamber must be able to maintain an atmospheric concentration of: *Oxygen supply at a minimum of 33.7 Litres per person per hour.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
There is a risk that the air supply will be severed and, consequently, an independent means of supply must be	Department of Industry and Resources, 2005 Refuge Chambers in Underground metalliferous mines – guideline: Safety

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.	and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge chamber should equipped with self-prepared oxygen supply system to ensure that the oxygen supply per person within the nominal protection time is not lower than 0.5L/min. It should also meet the following requirements: *(1) Compressed oxygen supply mode is the priority. Chemical oxygen should not be used as the main oxygen supply mode.* *(2) The oxygen level should be no lower than 99.8%, and meets the GB8982*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
The minimum Oxygen storage capacity of a refuge shall be sufficient to: *Provide 37.37L/hour per occupant for the specified occupancy duration of the refuge*	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.12.1.1.3 CARBON DIOXIDE REMOVAL

Carbon dioxide is being produced continuously by the cells of our body. The inability to expel this gas or an environment with high concentrations of carbon dioxide leads to carbon dioxide poisoning. Breathing air with more than 30% CO2 can quickly induce unconsciousness and cause death.
CO2 which is exhaled by chamber occupants must be removed by either constant flushing of the chamber with fresh air or by the recirculation of the chamber gas through a CO2 absorbent (scrubber).
A carbon dioxide scrubber must be provided within the refuge chamber to maintain levels within acceptable limits if the external compressed air supply is lost.
The acceptable carbon dioxide removal requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table

Table 4 – Acceptable Carbon dioxide removal Requirements

Carbon Dioxide Removal Requirements	***Relevant Standard***
A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide (CO2) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess CO2 and CO can be removed.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The refuge chamber must be able to supply carbon dioxide removal system that can remove 33.7 litres and hour per	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries.

person.	New South Wales Government Gazette No. 67
"Carbon dioxide removal systems or atmospheric renewal systems for normal operation shall have the capacity to maintain the partial pressure of carbon dioxide below 0.005 bar continuously based on a production rate of 0.05 Nm^3 per hour per diver" (refer sec 4, 602) The system shall be designed so as to minimise the build up of carbon dioxide. Dead space volume should be as low as possible. The partial pressure of carbon dioxide (ppCO2) shall be limited to 1 Pa. (Sec 4, H1003)	Offshore Standard DNV-OS-E402
*The Refuge Chamber should be equipped with effective air purification system and temperature and humidity regulating system, with the facility to remove harmful gas. The CO2 processing capacity is no less than 0.5l/min*per man;*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

The carbon dioxide (CO2) removal capacity of the scrubber should be sufficient to remove no less than 24 litres/ hour per person for the entrapment duration.
The maximum allowable CO2 level within the chamber is 1% (or 10000ppm)
Independent testing completed has verified the build up of CO2 within a refuge chamber and therefore confirms the need for a CO2 scrubbing system. Refer to appendix 3, 4 and 5.
Carbon dioxide is a colorless, odorless gas usually does not pose a direct hazard to life because it typically becomes diluted to low concentrations very quickly. But in certain circumstances, CO2 may become concentrated at levels lethal to people,
CO2 which is exhaled by chamber occupants must be removed by constant flushing of the chamber with fresh air or be the recirculation of the chamber gas through a CO2 absorbent (scrubber). If either of these mechanisms is inadequate, the occupants can develop CO2 toxicity by re-breathing their own exhaled CO2.
A rapid accumulation of CO2 may cause unconsciousness before any symptoms are experienced.
A slower build up causes a variety of symptoms, including:

- Shortness of breath, air hunger
- Flushing of the face and sweating
- Light headedness, jerks tremors or convulsions
- Impaired vision
- Head ache

The acceptable exposure limits for carbon dioxide are defined in various international standards, examples of which are listed in the below table

Table 4 - Standards for allowable carbon dioxide exposure levels

Exposure Limit		*Relevant Standard*
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
5000ppm	30,000ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment [NOHSC:1003(1995]
5000ppm	15,000ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
5000ppm	30,000ppm	United States Department of Labor – Occupational Health and Safety Administration
5000ppm	30,000ppm	National Institute of Occupational Safety and Health - USA
5000ppm	30,000ppm	American conference of Governmental Industrial Hygienists
5000ppm	-	"Grenzwerte am Arbeitsplatz" published by the Swiss National Insurance Fund (SUVA),
5000ppm	-	Japanese Journal of Occupational Health
5000ppm	-	Arbejdstilsynet (Central Labour Inspectorate) Norway

7.15.12.1.1.4 CARBON MONOXIDE REMOVAL

Carbon monoxide is an asphyxiant and is endogenously produced in humans at varying levels depending on different health factors (i.e. smokers, obesity, hypertension, anemia, age). Refer to appendix 10.

Inhalation of carbon monoxide causes cellular hypoxia by preventing blood from carrying sufficient oxygen. Carbon monoxide combines reversibly with hemoglobin to form carboxyhaemoglobin.

A carboxyhaemoglobin level of 0.4 to 0.7 percent is normally present in the blood of adults. In cigarette / cigar smokers, the range is 4 to 20 percent. Carboxyhaemaglobin level is dependent mainly on the following:

- Concentration of CO in the air
- Duration of exposure
- Ventilation rate
- Pre-inhalation carboxyhaemaglobin level

Carbon monoxide exposure exerts its main toxic effect via its ability to interfere with organs that have a high metabolic demand for oxygen. High atmospheric concentrations leading to

carboxyhaemaglobin levels of 50 – 60 percent are likely to lead to unconsciousness and convulsions. Collapse may occur very quickly. A carboxyhaemaglobin level of 70 – 80 percent is probably incompatible with life. Refer to appendix 7 and 8.

Carbon monoxide removal systems or atmospheric renewal systems shall be provided within the refuge chamber to maintain levels below the maximum exposure limit of 30ppm. Refer to appendix 8.

The acceptable carbon monoxide removal requirements are defined in various international standards, examples of which are listed in the below table

Table 5 – Acceptable carbon monoxide removal requirements

Carbon Monoxide Removal Requirements	***Relevant Standard***
A CO Scrubber system that removes any harmful CO that may accumulate in the chamber, from sources such as – *People within the chamber* *Systems within the chamber; and* *People entering or exiting the chamber when the external environmental concentration of CO is at least 400ppm*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide (CO2) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess CO2 and CO can be removed.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chambers built for Chinese Coal Mines be equipped with an effective air purification system with the facility to remove CO. The air purification system must guarantee to decrease the CO intensity from 0.04% to below 0.0024% within 20 minutes.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

The acceptable exposure limits for carbon monoxide are defined in various international standards, examples of which are listed in the below table

Table 6 - Standards for allowable carbon monoxide exposure limits

Exposure Limit		***Relevant Standard***
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
30ppm	200ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment

		[NOHSC:1003(1995]
30ppm	200ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
35ppm	200ppm	National Institute of Occupational Safety and Health - USA
50ppm		United States Department of Labor – Occupational Health and Safety Administration

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied mine refuge chamber. Results indicated a steady increase in carbon monoxide concentration within the chamber. Refer to appendix 4.
Further independent testing was completed by ECS Stack Pty Ltd. During these tests the CO levels within the chamber displayed a steady increase. Refer to appendix 5 and 6.
The Safety in Mines Research Advisory Committee (SIMRAC) found in their assessment of refuge bay designs in collieries that without ventilation in a refuge bay, due to contamination from door openings and leaking to the inside of the bay, carbon monoxide could reach the threshold limit value (TLV) within 8.5 hours. They also found that where workers are to stay for longer periods there must be a method to flush out the air or create a positive pressure inside the bay. The use of oxygen may not be sufficient to ensure that the level of CO and CO2 caused by exhaled breath does not reach dangerous limits. Refer to appendix 9.

7.15.12.1.1.5 COOLING AND DEHUMIDIFYING

The healthy human body maintains its internal temperature around 37°C. Variations, usually of less than 1°C, occur with the time of the day, level of physical activity or emotional state. A change of body temperature exceeding 1°C occurs only during illness or when environmental conditions surpass the body's ability to cope with extreme temperatures.

As the environment warms-up, the body tends to warm-up as well. The body's internal "thermostat" maintains a constant inner body temperature by pumping more blood to the skin and by increasing sweat production. In this way, the body increases the rate of heat loss to balance the heat burden created by the environment. In a very hot environment, the rate of "heat gain" exceeds the rate of "heat loss" and the body temperature begins to rise. A rise in the body temperature results in heat illnesses.

When a worker is subject to extreme conditions over a period of time, heat disorders and health effects will be experienced. Refer to appendix 1.

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied mine refuge chamber. The main purpose of this test was to determine the requirement for cooling in an occupied and sealed environment without air conditioning. Testing was stopped after two hours due to the heat within the chamber reaching 60°C Refer to appendix 4.
The method of computation and interpretation of thermal balance is described in ISO 7933 International Standard – Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Heat Stress Using Calculation of the Predicted Heat Strain. Refer appendix 14.
MineARC recommends that a cooling capacity of 117 watts per person be maintained.
The acceptable cooling requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table

Table 7 - Standards for acceptable cooling requirements

Cooling Requirements	***Relevant Standard***

The refuge chamber must be provided with the following requirements: *Maintain an apparent temperature less than 35 degrees Celsius, taking into account –* *All internal heat loads (such a people, lighting, self rescuers, heat generated by scrubbing systems or other life support systems)* *External environmental conditions* *A minimum metabolic heat input of 117 watts per person; and* *Minimum humidity of 1.5 litres of water per day per person.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
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. Refridgerative 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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge Chamber should be equipped with effective air purification system and temperature and humidity regulating system. Within the nominal protection time, the internal oxygen, harmful gas intensity and apparent temperature should be ≤35%	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training
Apparent temperature in the fully occupied refuge chamber must not exceed 95 degrees Fahrenheit	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.12.1.1.6 ATMOSPHERIC MONITORING

The refuge chamber must be equipped with an internal and external environmental monitoring system. In case of emergency, it must be able to monitor the O2, CO2, CO, CH4 (methane), temperature and humidity.

Environmental monitoring shall be provided within the refuge chamber to ensure that levels inside the refuge chamber are below the maximum exposure limit.
The acceptable environmental monitoring requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table
Table 8 - Standards for acceptable environmental monitoring in refuge chambers.

Environmental monitoring requirements	***Relevant Standard***
Parameters that could jeopardize the safety of divers, and or violate the integrity of a diving system, shall be monitored and evaluated with a frequency that enables remedial actions to be carried out before personal harm is done or the system is damaged. *Oxygen analyzing systems shall have an accuracy of at least +/-0.015 bar partial pressure oxygen.* *Carbon dioxide analyzing systems shall have an accuracy of +/-0.01 bar partial pressure.*	Offshore Standard DNV-OS-E402
The refuge chamber should be equipped with Independent internal and external environment parameter monitoring system. In case of emergency, it can monitor the O2, CO in the airlock, the O2, CH4, CO2, CO, temperature, humidity and pressure difference in the life support compartment, and the O2, CH4, CO2, CO outside the chamber. *When using portable sensor for testing the outside environment parameter, reliable safety measures should be applied. When making monitoring with gas sampling, the gas sample should not be released inside the chamber.* *02 analysis sensor or test device must have an accuracy of 0.1%* *CO2 analyser must have accuracy within 0.1%* *CO analyser must have accuracy within 2%*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Air monitoring equipment with the ability to monitor CO2, CO, O2, CH4 inside and outside the refuge.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

Provide the ability to monitor carbon monoxide and oxygen inside and outside the shelter/chamber;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.13 CAPACITY

Refuge chamber manufacturers should specify the life supporting capacity of each chamber including number of occupants and duration of entrapment.

7.15.13.1.1 OCCUPANCY

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 an emergency. 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

The entry of additional persons beyond the rated capacity will reduce the entrapment duration of the refuge chamber.

7.15.13.1.2 DURATION

The nominal duration means the minimum number of hours that a refuge chamber meets the performance criteria at its rated capacity and at maximum operating conditions e.g ambient temperature.

The refuge chamber must be rated by the manufacturer for compliance with design and performance standards and specify its maximum operational range.

The refuge chamber supplies the maximum number of occupants as specified by the manufacturer with breathable air, cooling and water for each occupant for a minimum specified duration in stand-alone mode (without external air or power supply). This duration is to be determined by the mine's ERP.

The acceptable duration requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table

Table 9 - Standards for duration requirements

Duration Requirements	***Relevant Standard***
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The nominal protection time of refuge chamber isn't lower than 96h, with the safety factor more than 1.1 times.	Industrial standard in safety production for the people's republic of china State Administration of Work

	Safety (SAWS)
The breathable air sustains each person for 96 hours.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
Provide a minimum of 48 hours life support (air, water, emergency medical supplies, and food) for the maximum number of miners reasonably expected on the working section;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.14 ANCILLARY EQUIPMENT

7.15.14.1 FIRST AID KIT

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.

7.15.14.1.1 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

7.15.14.1.2 SANITATION

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 minimum stay of 36 hours in the refuge 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.

7.15.14.1.3 CONSUMABLES

7.15.14.1.3.1 WATER

People can survive for long periods without food but the human body is ill-equipped to cope with dehydration, which affects decision making
Water shall be provided within the refuge chamber for the maximum number of occupants for the maximum duration of the chamber.
MineARC recommends that no less than 1.5 litre per person per 24 hours is provided.
The acceptable water requirements for occupants of an underground refuge chamber are defined in various international standards, examples of which are listed in the below table

Table 9 - Standards for acceptable cooling requirements

Water Requirements	***Relevant Standard***
A minimum of 2.25L per person per 24 hours must be supplied up to the maximum duration of the refuge chamber	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp
Drinking water not less than 1.5L/man per day.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide a minimum eight quarts of water per miner;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training
Supply of potable water (A minimum of 2 litres per person per 24 hours is recommended)	Directive B5 – Department of Mineral and Energy Affairs – South Africa

7.15.15 DESIGN AND CONSTRUCTION

7.15.15.1.1 STRUCTURAL INTEGRITY

Refuge chambers are to provide a safe environment for mine workers in the event of an underground emergency. It therefore follows that the chamber itself should be sufficiently robust to remain operational following such an incident
Explosions are a major risk in coal mines and any refuge chamber that is to be deployed must be built to withstand an explosion.
Explosions occur by the oxidisation of coal particles, methane or other combustible materials within a coal mine which results in a rapid expansion of gas causing an explosive pressure pulse to travel within the mine.
The matter is exacerbated when a coal dust explosion occurs. Firstly the charge mass is now increased due to the coal dust acting as fuel, and secondly the explosive is actually caused by the mechanical action of gases (the coal dust is being lifted into the air). Instead of the explosive being depleted during the chemical reaction, it is being supplemented as the explosion progresses, which leads to the phenomena of the peak pressure actually increasing with the distance that the explosion

travels. This will continue until the fuel or oxygen is depleted, after which the explosion will reduce. Refer to appendix 9.
Another effect of an explosion, is a resultant negative pressure. This is almost instantaneously following an explosive blast and is caused by the resultant velocity and momentum of expanded gases. The negative pressure is usually significantly smaller and longer in duration than the positive phase but should still be considered in the design of a refuge chamber. An example explosive pressure pulse is shown below:

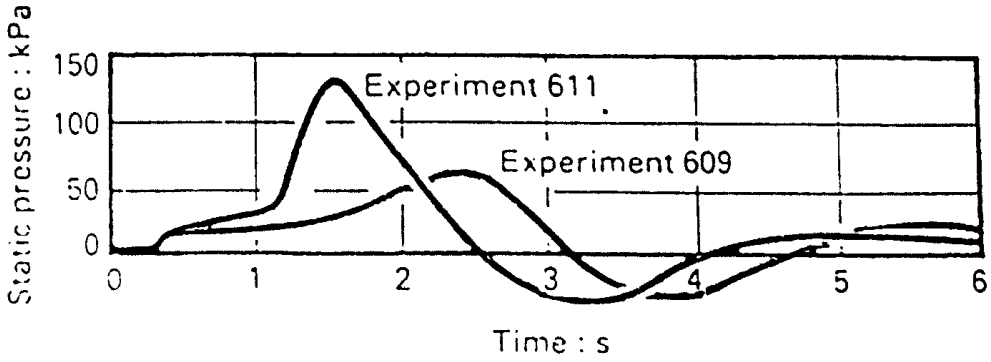

Figure 1 – Explosion pressure pulse

Refuge chambers to be deployed in a coal mine should at a minimum be able to withstand a minimum of 15psi overpressure as explosions with greater maximum pressure can result in fatalities. Refer appendix 9

Critical Event[42]	Related Max Pressure psi (kPa)
Felt as a sudden blow	2 (14)
Eardrum failure	5 (35)
Person knocked off feet	6 (42)
Lung damage threshold	15 (105)
Lethality:	
threshold	30-42 (210-294)
50 %	42-57 (294-399)
95-100	50-90 (350-630)

Figure 2 – Effect of pressure critical events.

Pressure rating within the mine should be risk assessed and higher rated chambers should be considered.
Refuge chambers must be able to withstand explosive over pressure but should also be designed to withstand the resultant negative pressure.
MineARC recommends that refuge chambers for coal mines be designed to withstand 25% negative pressure following a positive pressure blast (3.75 PSI)
The acceptable positive pressure limits are defined in various international standards, examples of which are listed in the below table:

Table 10 - Standards for overpressure requirements in refuge chambers

Requirements	***Standard***
Refuge chamber should have enough strength. The explosion proof capability is no less than 0.3MPa, that is, under the condition that the	Industrial standard in safety production for the people's republic of china State Administration of Work

operation time is no less than 300ms, the maximum peak overpressure of flow field pressure load that refuge chamber can withstand is no less than 0.3MPa.	Safety (SAWS)
Be capable of surviving an initial event with a peak overpressure of 15 psi for 3 seconds	WV
Be designed and made to withstand 15 pounds per square inch overpressure for 0.2 seconds prior to deployment.	MSHA Final Rule
Refuge bays must be of robust construction and where there is a high risk of explosion it must be able to withstand the effects of such an explosion	Directive B5 – Department of Mineeal and Energy Affairs – South Africa

7.15.15.1.2 DOORS AND HATCHES

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 maintained and monitored in good condition. During transport between underground locations, the structure may flex, causing doorframes to distort and welded seams to crack. The refuge chamber structure should be sufficiently rigid to resist this flexing and the damage it can cause. After a refuge chamber has been relocated, all seals should be fully tested before it is returned to service.

The sealing of a refuge 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 station 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 station 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 atmosphere.

7.15.15.1.3 EMERGENCY EXIT

A refuge chamber is to be fitted with a minimum of two means of egress. Due to the risk of the main access door being blocked by rock fall, vehicle or other obstacle. A secondary emergency exit should be provided with an inwards opening hatch.

The design of the refuge chamber must provide for:

- A primary means of egress that is capable of allowing a stretcher to enter and to exit.

- A secondary emergency exit in case the primary exit has been blocked. This must have a door that opens inwards and is to be located as far as practical from the main entrance.

The acceptable secondary means of egress for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table 11 - Standards for secondary means of egress

Requirements	***Standard***
The design of the refuge chamber must provide for *A primary means of egress that is capable of allowing a stretcher to enter and exit.* *A second emergency exit incase the primary exit has been blocked.* *The primary means of egress must not allow harmful amounts of gases to enter the refuge chamber*	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resounces Western Australia, 32 pp.
The refuge chamber should be provided with emergency escape hatch, to ensure the refuge people's escape when the entry door cannot be opened normally. The dimension of the emergency escape hatch is between 0.25 – 0.30m2, and is not recommended to be on the same side as the entry door.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide a means for entry and exit that maintains the integrity of the internal atmosphere;	WV

7.15.15.1.4 AIRLOCK

An airlock is required to prevent the ingress of toxlc gases into the occupied space of the refuge chamber.
An airlock system should incorporate a double-door design. The entry door opens externally due to positive pressure from the airlock flushing system. The airlock door opens inwards to the main refuge chamber.
When the airlock is flushed it must reduce or remove contaminants to within acceptable levels as defined in section 7.15.3 Atmosphere.

7.15.15.1.5 PRESSURE EQUALISATION

The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200Pa greater than the outside environment. This will prevent the ingress of toxic gases into the chamber. Over pressure protection should also be installed.
The acceptable level of pressure equalisation for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table 12 - Standards for secondary means of egress

Requirements	***Standard***
Maintain a positive pressure nominally 1.75kPa greater than the outside environment, over-pressurisation protection ie to be able to safely discharge excess air from the refuge chamber	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resounces Western Australia, 32 pp.
Refuge chamber should have enough air tightness. At the pressure of 500Pa, pressure relief rate is no larger than 350Pa/h. The internal air pressure should be kept 100 – 500Pa higher than the outside air pressure, and is adjustable according to actual situation.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Include an airlock that creates a barrier and isolates the interior space from the mine atmosphere, except for a refuge alternative capable of maintaining adequate positive pressure.	MSHA Final Rule
Refuge bays must be air leak proof, sealed in such a way so as to ensure a positive pressure when in use	Directive B5 – Department of Mineeal and Energy Affairs – South Africa
A pressure control system is to be used to prevent the internal pressure at any point in the diving system rising to excessive levels, or falling below prescribed levels. The pressure control system comprises the pressure regulating systems, pressure safety systems and associated instrumentation and alarm systems.	Offshore Standard DNV-OS-E402

7.15.15.1.6 VIEW PORT

The provision of a window for 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. All external windows should be explosion rated to 15psi and its retaining structure must be capable of withstanding external overpressure, particularly that caused by blasting. It is recommended that view ports be installed in the airlock as well as the main chamber to verify that the main chamber or airlock are in use.

7.15.15.1.7 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 over a period of time can be detrimental to health. Consequently, it is advisable to use a water-based epoxy paint, which on curing does not emit contaminants.

7.15.15.1.8 EXCLUSION OF FLAMMABLE MATERIALS

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

7.15.15.1.9 ELECTRICAL EQUIPMENT

All electrical equipment associated with the refuge chamber must be intrinsically safe in accordance with AS/NZS 60079 – intrinsically safe (i)

7.15.15.1.10 STROBE LIGHT

Darkness is inevitable in an underground environment and can be increased to a level of virtual impenetrability by smoke from a fire. This can make the refuge chamber difficult to locate by people seeking safety. An intrinsically safe high-intensity strobe light fitted close to the door of the chamber can make it easier to find in smoky conditions.

7.15.15.1.11 INTERNAL LIGHTING

Chemical light sticks or intrinsically safe cap lamps can provide adequate lighting for occupants within a chamber.

7.15.15.1.12 SEATING

Adequate seating is to be supplied for the maximum number of occupants. Allocated seating space is to be 600mm x 600mm including leg space per occupant.

7.15.15.2 LOCATION

A refuge chamber is designed to protect the lives of the underground workforce and is used as a safe area for evacuation in an emergency. Its correct location and capacity is critical to the success of the designed system. Although the positioning of a refuge chamber is strongly governed by its accessibility for people, its selected location is crucial for its ability to function correctly in the event of an emergency.

7.15.15.2.1 DISTANCE FROM THE WORKPLACE

MineARC Systems recommends that refuge chambers 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 pace, using 50% of the nominal duration of the SCSR. If it is assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety.
This distance should be regarded as an absolute maximum because:

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

It should be noted that crawling is necessarily slower than moderate walking, and should be allowed for where applicable.

7.15.15.2.1.1 NOMINAL DURATION OF SCSR's

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 attempts to build a realistic and practical safety margin into the duration of SCSRs. See appendix 11.

7.15.15.2.2 SAFETY OF LOCATION

7.15.15.2.2.1 EXPOSURE TO HAZARDS

Although the positioning of a refuge chamber is strongly governed by its accessibility for people in need of its protection, any potential susceptibility of its location to the hazards of rock fall, 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.

7.15.15.2.2.2 GROUND CONDITIONS

While it is recognised that it may be impossible to locate a refuge chamber excavation in an area free from normal rock mass 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, rock mass 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.

7.15.15.2.2.3 WATER

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.

7.15.16 CERTIFICATION AND MAINTENANCE

7.15.16.1 MAINTENANCE

For a refuge to fulfill 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 and due to the highly corrosive and abrasive atmosphere, chambers should be inspected regularly and basic tests carried out (minimum four monthly) to ensure full functionality or as per the manufacturer’s recommendations.
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. Any repair or maintenance work will devolve to the engineering personnel, who should have access to the necessary information and equipment to undertake their duties.

7.15.16.2 COMMISSIONING

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 four month intervals.
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.

7.15.16.3 CERTIFICATION

MineARC Systems recommends that manufacturers have their refuge chamber designs certified and approved by the relevant regulatory authority before they may be deployed in underground mines. This is to ensure that refuge chambers being used within Australian mines can meet the specified performance criteria outlined in the legislation. Manned testing should be completed to verify the life support capacity of the refuge chamber for a minimum of 1/3 of its rated duration, in stand alone mode. All tests should be verified by an independent body to the satisfaction of the regulatory authority.

7.15.17 SUMMARY

During an emergency situation, the first priority for all underground personnel should be to exit the mine via predetermined escape routes and egresses. However, emergency situations have occurred in the past, and the potential remains, in which personnel have become cut off and/or left unable to exit the mine themselves.

Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas (such as methane) can block escape routes and leave personnel injured or simply overwhelmed.

Typically, SCSR's only provide 30 minutes breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed with no impediments. With many underground networks extending over a number of kilometres, exiting the mine during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury, and for those who may be assisting them.

To counter this risk, it has been proposed here in this document that emergency refuge chambers form an integral part of an underground mine's wider Emergency Response Plan (ERP). Refuge chambers should be designed to provide a safe and secure 'go-to' area for personnel to gather and await extraction in the event of an emergency.

A refuge chamber is a manufactured rigid vessel that is outfitted with supplies and equipment capable of sustaining life for a period of time (potentially days) while miners await rescue.

A suitable refuge chamber therefore has the following design requirements:

Breathable Air Supply:
Refuge chambers should be fitted with an external compressed air supply as its primary means of life-support. The external air supply should be sufficient to provide a minimum of 0.09m^3/min per person
The environment within a refuge chamber should therefore be maintained with oxygen content between acceptable limits. The acceptable range is between 19.5% and 23.5%
In the event of external air supply being lost a secondary oxygen supply should be installed to provide a minimum of 0.5L per person per minute.
Carbon dioxide removal systems shall be provided within the refuge chamber to maintain levels below 1%.
Carbon monoxide removal systems shall also be provided within the refuge chamber to maintain levels below 30ppm.
Cooling:
The acceptable cooling requirements for underground refuge chambers are defined in various international standards, All refuge chamber designs must take into account all internal heat loads such as people, lighting, heat generated by scrubbing systems, external environmental conditions, a minimum metabolic heat input of 117 watts per person; and minimum humidity of 1.5 litres of water per day per person.
Atmospheric Monitoring:

The refuge chamber must be equipped with independent internal and external environment monitoring systems. In case of emergency, it must be able to monitor the O2, CO2, CO, CH4 in the refuge chamber.

Capacity and Safe Entrapment Duration:
The manufacturer should specify the nominal duration of the refuge chamber. The nominal duration means the minimum number of hours that a refuge chamber meets the performance criteria at its rated capacity and at maximum operating conditions e.g. ambient temperature.
The refuge chamber must supply the maximum number of occupants as specified by the manufacturer with breathable air, cooling and water for each occupant for a specified minimum duration in stand-alone mode (without external air or power supply). Required duration is to be determined by the mine's ERP.

Structural Integrity:
The construction of a refuge chamber should allow for the circumstances in which it will be used. The chamber and its equipment mountings must be very robust
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 maintained and monitored in good condition.
The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200 Pa greater than the outside environment. This will prevent the ingress of toxic gases into the chamber. Over pressure protection should also be installed.
Electrical equipment:
All electrical equipment associated with the refuge chamber must be intrinsically safe in accordance with AS/NZS 60079 – intrinsically safe (i)
Refuge Chamber Positioning:
Although the positioning of a refuge chamber is strongly governed by its accessibility for people, its selected location is crucial for its ability to function correctly in the event of an emergency. If it is

assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety. This distance should be regarded as an absolute maximum.

Inspection and Maintenance:

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

Certification:

MineARC Systems recommends that manufacturers have their refuge chamber designs certified by the relevant regulatory authority to ensure that products being used within mines can meet the specified performance criteria.

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APPENDIX 1 – HEAT DISORDERS AND HEALTH EFFECTS

When a worker is subject to extreme conditions over a period of time, the following heat disorders and health effects will be experienced. (United States Department of Labor Directive TED 01 – 00 – 015 OSHA Technical Manual Chapter III)

II. HEAT DISORDERS AND HEALTH EFFECTS.

A. **HEAT STROKE** occurs when the body's system of temperature regulation fails and body temperature rises to critical levels. This condition is caused by a combination of highly variable factors, and its occurrence is difficult to predict. Heat stroke is a medical emergency. The primary signs and symptoms of heat stroke are confusion; irrational behavior; loss of consciousness; convulsions; a lack of sweating (usually); hot, dry skin; and an abnormally high body temperature, e.g., a rectal temperature of 41°C (105.8°F). If body temperature is too high, it causes death. The elevated metabolic temperatures caused by a combination of work load and environmental heat load, both of which contribute to heat stroke, are also highly variable and difficult to predict.

If a worker shows signs of possible heat stroke, professional medical treatment should be obtained immediately. The worker should be placed in a shady area and the outer clothing should be removed. The worker's skin should be wetted and air movement around the worker should be increased to improve evaporative cooling until professional methods of cooling are initiated and the seriousness of the condition can be assessed. Fluids should be replaced as soon as possible. The medical outcome of an episode of heat stroke depends on the victim's physical fitness and the timing and effectiveness of first aid treatment.

Regardless of the worker's protests, no employee suspected of being ill from heat stroke should be sent home or left unattended unless a physician has specifically approved such an order.

B. **HEAT EXHAUSTION**. The signs and symptoms of heat exhaustion are headache, nausea, vertigo, weakness, thirst, and giddiness. Fortunately, this condition responds readily to prompt treatment. Heat exhaustion should not be dismissed lightly, however, for several reasons. One is that the fainting associated with heat exhaustion can be dangerous because the victim may be operating machinery or controlling an operation that should not be left unattended; moreover, the victim may be injured when he or she faints. Also, the signs and symptoms seen in heat exhaustion are

similar to those of heat stroke, a medical emergency.

Workers suffering from heat exhaustion should be removed from the hot environment and given fluid replacement. They should also be encouraged to get adequate rest.

C. **HEAT CRAMPS** are usually caused by performing hard physical labor in a hot environment. These cramps have been attributed to an electrolyte imbalance caused by sweating. It is important to understand that cramps can be caused by both too much and too little salt. Cramps appear to be caused by the lack of water replenishment. Because sweat is a hypotonic solution (±0.3% NaCl), excess salt can build up in the body if the water lost through sweating is not replaced. Thirst cannot be relied on as a guide to the need for water; instead, water must be taken every 15 to 20 minutes in hot environments.

Under extreme conditions, such as working for 6 to 8 hours in heavy protective gear, a loss of sodium may occur. Recent studies have shown that drinking commercially available carbohydrate-electrolyte replacement liquids is effective in minimizing physiological disturbances during recovery.

D. **HEAT COLLAPSE** ("Fainting"). In heat collapse, the brain does not receive enough oxygen because blood pools in the extremities. As a result, the exposed individual may lose consciousness. This reaction is similar to that of heat exhaustion and does not affect the body's heat balance. However, the onset of heat collapse is rapid and unpredictable. To prevent heat collapse, the worker should gradually become acclimatized to the hot environment.

E. **HEAT RASHES** are the most common problem in hot work environments. Prickly heat is manifested as red papules and usually appears in areas where the clothing is restrictive. As sweating increases, these papules give rise to a prickling sensation. Prickly heat occurs in skin that is persistently wetted by unevaporated sweat, and heat rash papules may become infected if they are not treated. In most cases, heat rashes will disappear when the affected individual returns to a cool environment.

F. **HEAT FATIGUE**. A factor that predisposes an individual to heat fatigue is lack of acclimatization. The use of a program of acclimatization and training for work in hot environments is advisable. The signs and symptoms of heat fatigue include impaired performance of skilled sensorimotor, mental, or vigilance jobs. There is no treatment for heat fatigue except to remove the heat stress before a more serious heat-related condition develops.

APPENDIX 2 – MINE INCIDENTS

APPENDIX 3 – RESEARCH PAPER, INTEGRATION OF SELF AND AIDED RESUE

APPENDIX 4 TEST REPORT 18050 REFUGE CHAMBER THERMAL STUDY

APPENDIX 5 TEST REPORT R09289 MINEARC UNDERGROUND GAS TESTING

APPENDIX 6 TEST REPORT R08281 MINEARC UNDERGROUND ATMOSPHERE TESTING

APPENDIX 7 OCCUPATIONAL SAFETY AND HEALTH GUIDELINE FOR CARBON MONOXIDE

APPENDIX 8 EXPOSURE STANDARD DOCUMENTATION FOR CARBON MONOXIDE

APPENDIX 9 SIMRAC PROJECT REPORT COL 115 – ASSESSMENT OF REFUGE BAY DESIGNS IN COLLIERIES

APPENDIX 10 RESEARCH PAPER ENDOGENOUS CARBON MONOXIDE PRODUCTION IN MAN

APPENDIX 11 – REPORT INTO SELF AIDED RECUE

APPENDIX 12 – RESEARCH REPORT INTO EXPLOSIVITY

APPENDIX 13 – WESTERN AUSTRALIAN GUIDELINE FOR REFUGE CHAMBERS IN METALLIFEROUS MINES

APPENDIX 14 – ISO STANDARD – ASSESSMENT OF HEAT STRESS

FINAL DRAFT hardrock chamber COP

CONTENTS:

Public comments on Draft Code of Practice
EMERGENCY RESPONSE AT AUSTRALIAN MINES

INTRODUCTION

Established in 1999, MineARC Systems is now the global leader in the manufacture and supply of emergency refuge chambers to the underground mining, tunneling, nuclear and chemical processing industries.

Emergency refuge chambers form an integral part of an underground mine, tunnel, nuclear or chemical operation's wider Emergency Response Plan (ERP). Fires, explosions, rock-falls, flooding, and the release of smoke and other forms of toxic gas are the types of industrial incidents that occur all too frequently, (refer to appendix 2) despite the high levels of planning and safety precautions in place.

In these types of emergencies, when evacuation is no-longer safe or practical, emergency refuge chambers are designed to provide a safe and secure 'go-to' area for personnel to gather and await extraction. MineARC refuge chambers have been successfully used around the world in multiple mine and tunneling emergencies to save lives. Refer to appendix 2.

Inside a standard MineARC refuge chamber a number of vital life support systems combine to create a safe and secure ongoing environment for occupants, including; oxygen supply, carbon dioxide (CO_2) and carbon monoxide (CO) scrubbing, cooling and gas monitoring.

Today MineARC has offices and manufacturing facilities in Perth, Western Australia; Santiago, Chile; Fushun, China; Pretoria in South Africa and Dallas in the United States, as well as a strong distribution network worldwide. In all, MineARC manufactures refuge chambers for operations in over 30 countries world-wide.

All MineARC refuge chambers comply with the highest international industry regulations, standards and guidelines.

MineARC hard-rock refuge chambers comply in full with the West Australian Department of Mines & Petroleum (DMP) industry Guidelines. MineARC hard-rock refuge chambers are also European CE and Australian C-Tick certified and is ISO9001 certified.

MineARC Systems would like to submit the following comments and recommendations for:
Draft Code of Practice – 7.15 Refuge Procedures - EMERGENCY RESPONSE AT AUSTRALIAN MINES

7.15A REFUGE PROCEDURES FOR HARD ROCK MINES

7.15.18 BACKGROUND

During an emergency situation, the first priority for all underground personnel should be to find a place of safe refuge. Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas can block escape routes and leave personnel injured or simply overwhelmed. Examples of incidents that have occurred can be found in appendix 2 of this document.

In an emergency situation personnel will be required to don breathing apparatus (self contained self rescuers (SCSR)), as smoke and other noxious gases contaminate the air. Typically, SCSR's only provide 30 minutes breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed with no impediments. Refer appendix 11. With many underground networks extending over a number of kilometres, travelling to a safe place of refuge during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury, and for those who may be assisting them.

Personnel are also naturally more likely to be anxious, breathing more heavily and therefore consuming more oxygen. Added to this would be the potential for injury, levels of disorientation and a lack of visibility due to smoke and other airborne particles.

Taking into consideration all the above, a change-over of breathing apparatus or sustained entrapment could well be required by personnel within the mine.

To counter this level of risk, a 'network' of refuge chambers deployed strategically throughout an underground mine, is now recognised as industry best practice.

7.15.18.1 RISK STATEMENT

All mines to which this Code of Practice applies must be able to demonstrate that their emergency plans provide for the hazards associated with irrespirable atmospheres (refer to Nature of the Hazard), by installing suitable underground refuge chambers, and that these refuge chambers be effectively managed and maintained.

Effective risk management procedure is essential in preventing injuries and fatalities, and should abide by the following key principles:

- First: Identifying all potential hazards
- Second: Assessing the resulting risk(s) associated

- Third: Implementation of both preventative and responsive measures necessary to minimise the level of risk of harm and/or health to personnel.

7.15.18.2 NATURE OF THE HAZARD

The serious potential hazards associated with underground mining are well known to the industry. These include fires and explosions (resulting in extreme temperatures, smoke and other airborne particles), flooding, fall of ground, and a build-up in noxious gases. All of which can lead to an irrespirable atmosphere occurring.

Such hazards can block escape routes and leave personnel injured or simply overwhelmed – limiting or preventing their ability to safely evacuate the mine. .

The majority of prior incidents resulting in injury and/or fatalities in the hard rock mining industry (globally) have been caused by the following: (refer Appendix 2 for direct reference case studies)

- Ignition sources; resulting in explosion and/or fire
- In rush and flooding
- Seismic events resulting in fall of ground

Furthermore, the widespread use of diesel-powered and electrical equipment in underground mines has led to a growing inventory of combustible materials present. 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.

In the event of an underground hazard in which the atmosphere becomes irrespirable, there is an immediate need to secure a safe and reliable supply of breathable air.
For this reason, most underground mine workers are supplied 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 (an irrespirable atmosphere), to a predetermined place of safe-refuge underground.

Commonly, SCSR's only provide 30 minutes of breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed, with no impediments (refer appendix 11). With many underground networks extending over a number of kilometres, travelling to a place of safe refuge during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury and for those who may be assisting them

During an emergency situation personnel are also more likely to be anxious, breathing more heavily and therefore consuming more oxygen. Added to this would be levels of disorientation, shock, as well as a potential lack of visibility due to smoke and other airborne particles.

Taking into consideration all the above, a change-over of breathing apparatus or a place of sustained entrapment could well be required by personnel within the mine.

To counter this level of risk, a 'network' of refuge chambers deployed strategically throughout an underground mine, is now recognised as industry best practice.

Emergency refuge chambers are designed to provide a long-term safety option where personnel can gather and await extraction. Additionally, refuge chambers can also be used to provide a safe and secure change-over-station for emergency response personnel as they attempt evacuation.

7.15.19 DEFINITIONS

7.15.19.1 REFUGE CHAMBER DEFINITION

A manufactured rigid vessel that is outfitted with supplies and equipment to sustain life for a period of time (potentially days) while mine workers wait for rescue. Miner workers take refuge in a chamber during an emergency.

As a basic requirement, a refuge chamber should therefore be robust in construction, fire resistant, and able to maintain a positively pressurized and sealed internal atmosphere. The refuge chamber should also be fitted with back-up air supply, CO/CO2 scrubbing and cooling capabilities. They must be capable of operating 'stand-alone' for a minimum of 36 hours, i.e. without being connected to a mine's 'mains' supply of air/power.

Depending on the size of the mine, the number of active workplaces and the number of personnel underground at any one time, multiple refuge chambers may be required, and should be deployed throughout the mine to create a 'network', accessible to all personnel.

7.15.20 REFUGE CHAMBER DESIGN REQUIREMENTS

This sections aims to give guidance on the conceptual and detailed design and operation of a refuge chamber.

7.15.20.1 ATMOSPHERE

A refuge chamber is to provide a safe respire able atmosphere independent of external mine conditions.
In basic terms, human breathing consumes oxygen and expels carbon dioxide, carbon monoxide, water vapor and heat. Therefore a life support system is required within the refuge chamber to replace the oxygen consumed and remove exhausted carbon dioxide, carbon monoxide, moisture and heat to maintain the atmosphere within acceptable limits.

7.15.20.1.1 PRIMARY LIFE SUPPORT

7.15.20.1.1.1 EXTERNAL COMPRESSED AIR

Refuge chambers should be fitted with an external compressed air supply as its primary means of life-support. In the event that the mine air supply continues to operate during an emergency, it will provide indefinite life support by continually renewing the chamber's internal atmosphere. The external air supply should be sufficient to provide a minimum of **0.09m^3/min per person** and compliant to Australian Standard AS NZS 1716:2003 Respiratory Protective Devices.
The acceptable air supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table:

Table 2 - Standards for acceptable air supply requirements

Air Supply Requirements	***Relevant Standard***
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 external atmosphere.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Refuge chamber should have interface to mine compressed-air system and configured facilities for decompression, noise elimination, filtration and control, ensuring the outlet pressure of mine compresses air system remains between 0.1—0.3MPa, air volume no less than 0.3m3/min per person and continuous noise not higher than 70dB(A).	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
A reliable source of respirable air must be supplied to the bay so as to ensure proper flushing and create a positive pressure. Where compressed air is used an arrangement for silencing must be made.	Directive B5 – Department of Mineral and Energy Affairs – South Africa

Following an emergency event such as rock fall, fire etc. It is possible for the external compressed air supply to be lost and therefore a secondary life support means in addition should be provided within the chamber.

7.15.20.1.1.2 SECONDARY LIFE SUPPORT

7.15.20.1.1.2.1 OXYGEN SUPPLY

Oxygen is a key requirement for cellular activity and therefore the absence of oxygen for relatively short periods of time will result in death. Humans within an enclosed environment consume oxygen and if not replaced would result in an irrespirable atmosphere. Additionally, high oxygen levels can result in oxygen toxicity causing disorientation, breathing problems and other medical conditions.
The environment within a refuge chamber should therefore be maintained with an oxygen content between acceptable limits. The acceptable range according to Australian standard AS2865-1995 "Safety in Confined Spaces" is between 19.5% and 23.5%.
The acceptable oxygen limits for a breathable environment are defined in various international standards, examples of which are listed in the below table:

Table 2 - Standards for allowable oxygen level

Minimum Oxygen Content (% by volume)	***Maximum Oxygen Content (% by volume)***	***Relevant Standard***
19.5%	23.5%	AS 2865 – 1995
19%	23%	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
18.5%	23.0%	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
18.5%	23.0%	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
19.5%		West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

In the event of external air supply being lost a secondary oxygen supply (compressed medical grade oxygen cylinders) should be installed to provide a minimum of 0.5L per person per minute for the intended occupancy and entrapment duration of the refuge chamber.
The provision of a third backup oxygen supply from oxygen candles is strongly recommended. Refer to appendix 13.
The acceptable oxygen supply requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table:

Table 3 – Acceptable Oxygen Supply Requirements

Oxygen Supply Requirements	***Relevant Standard***
The refuge chamber must be able to maintain an atmospheric concentration of: *Oxygen supply at a minimum of 33.7 Litres per person per hour.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metalliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge chamber should equipped with self-prepared oxygen supply system to ensure that the oxygen supply per person within the nominal protection time is not lower than 0.5L/min. It should also meet the following requirements: *(1) Compressed oxygen supply mode is the priority. Chemical oxygen should not be used as the main oxygen supply mode.* *(2) The oxygen level should be no lower than 99.8%, and meets the GB8982*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
The minimum Oxygen storage capacity of a refuge shall be sufficient to: *Provide 37.37L/hour per occupant for the specified occupancy duration of the refuge*	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.20.1.1.3 CARBON DIOXIDE REMOVAL

Carbon dioxide is being produced continuously by the cells of our body. The inability to expel this gas or an environment with high concentrations of carbon dioxide leads to carbon dioxide poisoning. Breathing air with more than 30% CO2 can quickly induce unconsciousness and cause death

CO2 which is exhaled by chamber occupants must be removed by either constant flushing of the chamber with fresh air or by the recirculation of the chamber gas through a CO2 absorbent (scrubber).

A carbon dioxide scrubber must be provided within the refuge chamber to maintain levels within acceptable limits if the external compressed air supply is lost.

The acceptable carbon dioxide removal requirements for a breathable environment are defined in various international standards, examples of which are listed in the below table:

Table 4 – Acceptable Carbon dioxide removal Requirements

Carbon Dioxide Removal Requirements	***Relevant Standard***
A respirable atmosphere can be provided by replenishing oxygen and scrubbing the atmosphere inside the chamber of excess carbon dioxide (CO2) and carbon monoxide (CO). Oxygen can be replenished by adding normal air, as long as the source remains available, and excess CO2 and CO can be removed.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metalliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The refuge chamber must be able to supply carbon dioxide removal system that can remove 33.7 litres and hour per person.	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
"Carbon dioxide removal systems or atmospheric renewal systems for normal operation shall have the capacity to maintain the partial pressure of carbon dioxide below 0.005 bar continuously based on a production rate of 0.05 Nm^3 per hour per diver" (refer sec 4, 602) *The system shall be designed so as to minimise the build up of carbon dioxide. Dead space volume should be as low as possible. The partial pressure of carbon dioxide (ppCO2) shall be limited to 1 Pa. (Sec 4, H1003)*	Offshore Standard DNV-OS-E402
*The Refuge Chamber should be equipped with effective air purification system and temperature and humidity regulating system, with the facility to remove harmful gas. The CO2 processing capacity is no less than 0.5l/min*per man;*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

The carbon dioxide (CO2) removal capacity of the scrubber should be sufficient to remove no less than 24 litres/ hour per person for the entrapment duration.
The maximum allowable CO2 level within the chamber is 1% (or 10,000ppm)
Independent testing completed has verified the build-up of CO2 within the refuge chamber and therefore confirms the need for a CO2 scrubber. Refer to appendix 4, 5 and 6.
Carbon dioxide is a colorless, odorless gas usually does not pose a direct hazard to life because it typically becomes diluted to low concentrations very quickly. But in certain circumstances, CO2 may become concentrated at levels lethal to people,
CO2 which is exhaled by chamber occupants must be removed by constant flushing of the chamber with fresh air or by the recirculation of the chamber gas through a CO2 absorbent (scrubber). If either of these mechanisms is inadequate, the occupants can develop CO2 toxicity by rebreathing their own exhaled CO2.

A rapid accumulation of CO2 may cause unconsciousness before any symptoms are experienced. A slower build up causes a variety of symptoms, including:

- Shortness of breath, air hunger
- Flushing of the face and sweating
- Light headedness, jerks tremors or convulsions
- Impaired vision
- Head ache

The acceptable exposure limits for carbon dioxide are defined in various international standards, examples of which are listed in the below table:

Table 5 - Standards for allowable carbon dioxide exposure levels

Exposure Limit		***Relevant Standard***
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
5000ppm	30,000ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment [NOHSC:1003(1995]
5000ppm	15,000ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
5000ppm	30,000ppm	United States Department of Labor – Occupational Health and Safety Administration
5000ppm	30,000ppm	National Institute of Occupational Safety and Health - USA
5000ppm	30,000ppm	American conference of Governmental Industrial Hygienists
5000ppm	-	"Grenzwerte am Arbeitsplatz" published by the Swiss National Insurance Fund (SUVA),
5000ppm	-	Japanese Journal of Occupational Health
5000ppm	-	Arbejdstilsynet (Central Labour Inspectorate) Norway

7.15.20.1.1.4 CARBON MONOXIDE REMOVAL

Carbon monoxide is an asphyxiant and is endogenously produced in humans at varying levels depending on different health factors (i.e. smokers, obesity, hypertension, anemia, age). Refer to appendix 10.

Inhalation of carbon monoxide causes cellular hypoxia by preventing blood from carrying sufficient oxygen. Carbon monoxide combines reversibly with hemoglobin to form carboxyhaemoglobin.
A carboxyhaemoglobin level of 0.4 to 0.7 percent is normally present in the blood of adults. In cigarette / cigar smokers, the range is 4 to 20 percent. Carboxyhaemaglobin level is dependent mainly on the following:

- Concentration of CO in the air
- Duration of exposure
- Ventilation rate
- Pre-inhalation carboxyhaemaglobin level

Carbon monoxide exposure exerts its main toxic effect via its ability to interfere with organs that have a high metabolic demand for oxygen. High atmospheric concentrations leading to carboxyhaemaglobin levels of 50 – 60 percent are likely to lead to unconsciousness and convulsions. Collapse may occur very quickly. A carboxyhaemaglobin level of 70 – 80 percent is probably incompatible with life. Refer to appendix 7 and 8.
Carbon monoxide removal systems or atmospheric renewal systems shall be provided within the refuge chamber to maintain levels below the maximum exposure limit of 30ppm. Refer to appendix 8
The acceptable carbon monoxide removal requirements are defined in various international standards, examples of which are listed in the below table:

Table 6 – Acceptable Carbon monoxide removal requirements

Carbon Monoxide Removal Requirements	***Relevant Standard***
A CO Scrubber system that removes any harmful CO that may accumulate in the chamber, from sources such as – *People within the chamber* *Systems within the chamber; and* *People entering or exiting the chamber when the external environmental concentration of CO is at least 400ppm*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
Refuge chambers built for Chinese Coal Mines be equipped with an effective air purification system with the facility to remove CO. The air purification system must guarantee to decrease the CO intensity from 0.04% to below 0.0024% within 20 minutes.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter	West Virginia Emergency Rule Governing Protective Clothing

atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	and Equipment West Virginia Office of Miners' Health, Safety and Training

The acceptable exposure limits for carbon monoxide are defined in various international standards, examples of which are listed in the below table:

Table 7 - Standards for allowable carbon monoxide exposure limits

Exposure Limit		***Relevant Standard***
Time-weighted average (TWA)	***Short term exposure limit (STEL)***	
30ppm	200ppm	Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment [NOHSC:1003(1995]
30ppm	200ppm	EH40/2005 Workplace exposure limits – Health and Safety Executive, United Kingdom
35ppm	200ppm	National Institute of Occupational Safety and Health – USA
50ppm	-	United States Department of Labor – Occupational Health and Safety Administration

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied mine refuge chamber. Results indicated a steady increase in carbon monoxide concentration within the chamber. Refer to appendix 4

Further independent testing was completed by ECS Stack Pty Ltd. During these tests the CO levels within the chamber displayed a steady increase. Refer to appendix 5 and 6.

The Safety in Mines Research Advisory Committee (SIMRAC) found in their assessment of refuge bay designs in collieries that without ventilation in a refuge bay, due to contamination from door openings and leaking to the inside of the bay, carbon monoxide could reach the TLV within 8.5 hours. They also found that where workers are to stay for longer periods there must be a method to flush out the air or create a positive pressure inside the bay. The use of oxygen may not be sufficient to ensure that the level of CO and CO2 caused by exhaled breath does not reach dangerous limits. Refer to appendix 9.

7.15.20.1.1.5 COOLING AND DEHUMIDIFYING

The healthy human body maintains its internal temperature around 37°C. Variations, usually of less than 1°C, occur with the time of the day, level of physical activity or emotional state. A change of body temperature exceeding 1°C occurs only during illness or when environmental conditions surpass the body's ability to cope with extreme temperatures.

As the environment warms-up, the body tends to warm-up as well. The body's internal "thermostat" maintains a constant inner body temperature by pumping more blood to the

skin and by increasing sweat production. In this way, the body increases the rate of heat loss to balance the heat burden created by the environment. In a very hot environment, the rate of "heat gain" exceeds the rate of "heat loss" and the body temperature begins to rise. A rise in the body temperature results in heat illnesses.

When a worker is subject to extreme conditions over a period of time, heat disorders and health effects will be experienced. Refer to appendix 1

MineARC Systems commissioned Industrial Hygiene and Safety Technology, Inc to assess the thermal environment of an occupied mine refuge chamber. The main purpose of this test was to determine the requirement for cooling in an occupied and sealed environment without air conditioning. Testing was stopped after two hours due to the heat within the chamber reaching 60°C. Refer to appendix 4.
The method of computation and interpretation of thermal balance is described in ISO 7933 International Standard – Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Heat Stress Using Calculation of the Predicted Heat Strain. Refer to appendix 14.
MineARC recommends that a cooling capacity of 117 watts per person be maintained.
The acceptable cooling requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table 7 - Standards for acceptable cooling requirements

Cooling Requirements	***Relevant Standard***
The refuge chamber must be provided with the following requirements: *Maintain an apparent temperature less than 35 degrees Celsius, taking into account –* *All internal heat loads (such a people, lighting, self rescuers, heat generated by scrubbing systems or other life support systems)* *External environmental conditions* *A minimum metabolic heat input of 117 watts per person; and* *Minimum humidity of 1.5 litres of water per day per person.*	Clause 107(2) (ii) of Occupational Health and Safety Regulations – Department of Primary Industries. New South Wales Government Gazette No. 67
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. Refridgerative 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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The Refuge Chamber should be	Industrial standard in safety

equipped with effective air purification system and temperature and humidity regulating system. Within the nominal protection time, the internal oxygen, harmful gas intensity and apparent temperature should be ≤35%	production for the people's republic of china State Administration of Work Safety (SAWS)
Provide for rapidly establishing and maintaining an internal shelter atmosphere of oxygen above 19.5%, carbon dioxide below 0.5%, carbon monoxide below 50 ppm, and an apparent-temperature of 95 degrees Fahrenheit;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training
Apparent temperature in the fully occupied refuge chamber must not exceed 95 degrees Fahrenheit	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration

7.15.20.1.1.6 ATMOSPHERIC MONITORING

The refuge chamber must be equipped with an internal environmental monitoring system. In case of emergency, it must be able to monitor the O2, CO2, CO and temperature in the main chamber.

Environmental monitoring shall be provided within the refuge chamber to ensure that levels inside the refuge chamber are below the maximum exposure limit. External atmospheric monitoring is also recommended.
The acceptable environmental monitoring requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:
Table 8 - Standards for acceptable environmental monitoring requirements for underground refuge chambers

Environmental monitoring Requirements	***Relevant Standard***
Parameters that could jeopardize the safety of divers, and or violate the integrity of a diving system, shall be monitored and evaluated with a frequency that enables remedial actions to be carried out before personal harm is done or the system is damaged. *Oxygen analyzing systems shall have an accuracy of at least +/-0.015 bar partial pressure oxygen.* *Carbon dioxide analyzing systems shall have an accuracy of +/-0.01 bar partial pressure.*	Offshore Standard DNV-OS-E402
The refuge chamber should be equipped with Independent internal and external environment parameter monitoring system. In case of emergency, it can monitor the O2, CO in the airlock, the O2, CH4, CO2, CO, temperature, humidity and pressure difference in the life support compartment, and the O2, CH4, CO2, CO outside the chamber. *When using portable sensor for testing the outside environment parameter, reliable safety measures should be applied. When making monitoring with gas sampling, the gas sample should not be released inside the chamber.* *02 analysis sensor or test device must have an accuracy of 0.1%* *CO2 analyser must have accuracy within 0.1%* *CO analyser must have accuracy within 2%*	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Air monitoring equipment with the ability to monitor CO2, CO, O2, CH4 inside and outside the refuge.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health

	Administration
Provide the ability to monitor carbon monoxide and oxygen inside and outside the shelter/chamber;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.21 CAPACITY

Refuge chamber manufacturers should specify the life supporting capacity of each chamber including number of occupants and duration of entrapment.

7.15.21.1.1.1 OCCUPANCY

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 an emergency. The chamber design 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

The entry of additional persons beyond the rated capacity will reduce the entrapment duration of the refuge chamber.

7.15.21.1.1.2 DURATION

The nominal duration means the minimum number of hours that a refuge chamber meets the performance criteria at its rated capacity and at maximum operating conditions, e.g. ambient temperature.
The refuge chamber must be rated by the manufacturer for compliance with design and performance standards and specify its maximum operational range.
The refuge chamber supplies the maximum number of occupants as specified by the manufacturer with breathable air, cooling and water for each occupant for a minimum of 36hours in stand-alone mode (without external air or power supply)
The acceptable duration requirements for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table 9 - Standards for duration requirements

Duration Requirements	***Relevant Standard***

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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The nominal protection time of refuge chamber isn't lower than 96h, with the safety factor more than 1.1 times.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
The breathable air sustains each person for 96 hours.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
Provide a minimum of 48 hours life support (air, water, emergency medical supplies, and food) for the maximum number of miners reasonably expected on the working section;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.22 ANCILLARY EQUIPMENT

7.15.22.1.1.1 FIRST AID KIT

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.

7.15.22.1.1.2 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

7.15.22.1.1.3 SANITATION

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 minimum stay of 36 hours in the refuge 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.

7.15.22.1.1.4 CONSUMABLES

7.15.22.1.1.4.1 WATER

People can survive for long periods without food but the human body is ill-equipped to cope with dehydration, which affects decision making
Water shall be provided within the refuge chamber for the maximum number of occupants for the maximum duration of the chamber.
MineARC recommends that no less than 1.5 litre per person per 24 hours is provided.
The acceptable water requirements for occupants of an underground refuge chamber are defined in various international standards, examples of which are listed in the below table:

Table (number) - Standards for acceptable cooling requirements

Water Requirements	***Relevant Standard***
A minimum of 2.25L per person per 24 hours must be supplied up to the maximum duration of the refuge chamber	Occupational Health and Safety Act – NSW Government Gazette No 67
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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp
Drinking water not less than 1.5L/man per day.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide a minimum eight quarts of water per miner;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training
Supply of potable water (A minimum of 2 litres per person per 24 hours is recommended)	Directive B5 – Department of Mineral and Energy Affairs – South Africa

7.15.23 DESIGN AND CONSTRUCTION

7.15.23.1.1.1 STRUCTURAL INTEGRITY

The construction of a refuge chamber should allow for the circumstances in which it will be used. Moveable chambers should be 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.

7.15.23.1.1.2 DOORS AND HATCHES

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 maintained and monitored in good condition. During transport between underground locations, the refuge chamber structure may flex, causing doorframes to distort and welded seams to crack. The refuge chamber structure should be sufficiently rigid to resist this flexing and the damage it can cause. After a refuge chamber has been relocated, all seals should be fully tested before it is returned to service.

The sealing of a refuge 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 refuge 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 refuge 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.

7.15.23.1.1.3 EMERGENCY EXIT

A refuge chamber must be fitted with a minimum of two means of egress. Due to the risk of the main access door being blocked by rock fall, vehicle or other obstacle. A secondary emergency exit should be provided with an inwards opening hatch.
The design of the refuge chamber must provide for:

- A primary means of egress that is capable of allowing a stretcher to enter and to exit.
- A secondary emergency exit in case the primary exit has been blocked. This must have a door that opens inwards and is to be located as far as practical from the main entrance.

The acceptable secondary means of egress for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table 11 - Standards for secondary means of egress

Requirements	***Standard***
The design of the refuge chamber must provide for	Occupational Health and Safety Act – NSW Government Gazette

A primary means of egress that is capable of allowing a stretcher to enter and exit. *A second emergency exit in case the primary exit has been blocked.* *The primary means of egress must not allow harmful amounts of gases to enter the refuge chamber*	No 67
Some risk assessments have identified the risk that the main access door could become blocked by a rock fall, 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.	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division, Department of Industry and Resources Western Australia, 32 pp.
The refuge chamber should be provided with emergency escape hatch, to ensure the refuge people's escape when the entry door cannot be opened normally. The dimension of the emergency escape hatch is between 0.25 – 0.30m2, and is not recommended to be on the same side as the entry door.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Provide a means for entry and exit that maintains the integrity of the internal atmosphere;	West Virginia Emergency Rule Governing Protective Clothing and Equipment West Virginia Office of Miners' Health, Safety and Training

7.15.23.1.1.4 PRESSURE EQUALISATION

The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200 Pa greater than the outside environment. This will prevent the ingress of toxic gases into the chamber. Over pressure protection should also be installed.
The acceptable level of pressure equalisation for underground refuge chambers are defined in various international standards, examples of which are listed in the below table:

Table (number) - Standards for secondary means of egress

Requirements	***Standard***
Maintain a positive pressure nominally 1.75kPa greater than the outside environment, over-pressurisation protection i.e. to be able to safely discharge excess air from the refuge chamber	Occupational Health and Safety Act – NSW Government Gazette No 67
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	Department of Industry and Resources, 2005 Refuge Chambers in Underground metaliferous mines – guideline: Safety and Health Division,

equalisation mechanism should be installed.	Department of Industry and Resources Western Australia, 32 pp.
Refuge chamber should have enough air tightness. At the pressure of 500Pa, pressure relief rate is no larger than 350Pa/h. The internal air pressure should be kept 100 – 500Pa higher than the outside air pressure, and is adjustable according to actual situation.	Industrial standard in safety production for the people's republic of china State Administration of Work Safety (SAWS)
Include an airlock that creates a barrier and isolates the interior space from the mine atmosphere, except for a refuge alternative capable of maintaining adequate positive pressure.	Refuge Alternatives for Underground Coal Mines; Final Rule Mines Safety and Health Administration
Refuge bays must be air leak proof, sealed in such a way so as to ensure a positive pressure when in use	Directive B5 – Department of Mineral and Energy Affairs – South Africa
A pressure control system is to be used to prevent the internal pressure at any point in the diving system rising to excessive levels, or falling below prescribed levels. The pressure control system comprises the pressure regulating systems, pressure safety systems and associated instrumentation and alarm systems.	Offshore Standard DNV-OS-E402

7.15.23.1.1.5 VIEW PORT

The provision of a window for 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.

7.15.23.1.1.6 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 over a period of time can be detrimental to health. Consequently, it is advisable to use a water-based epoxy paint, which on curing does not emit contaminants.

7.15.23.1.1.7 EXCLUSION OF FLAMMABLE MATERIALS

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

7.15.23.1.1.8 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 a minimum 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 alternating 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 3947.3:1994
- Combination fuse switch units incorporating high rupturing capacity (HRC) fuses - Australian Standard AS/NZS 3947.3:1994
- 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.

The Mines Safety and Inspection Regulations 1995 require all mains wiring installed underground to be metallically covered and earth-leakage protected

7.15.23.1.1.9 STROBE LIGHT

Darkness is inevitable in the underground environment and can be increased to a level of virtual impenetrability by smoke from a fire. This can make the refuge chamber difficult to locate by people seeking safety. A high-intensity strobe light should be fitted close to the door of the chamber can make it easier to find in smoky conditions.

7.15.23.1.1.10 INTERNAL LIGHTING

Adequate internal lighting should be installed into the refuge chamber.

7.15.23.1.1.11SEATING

Adequate seating is to be supplied for the maximum number of occupants. Allocated seating space is to be 600mm x 600mm per occupant including leg space.

7.15.24 LOCATION

A refuge chamber is designed to protect the lives of the underground workforce and is used as a safe area for evacuation in an emergency. Its correct location and capacity is critical to the success of the designed system. Although the positioning of a refuge chamber is strongly governed by its accessibility for people, its selected location is crucial for its ability to function correctly in the event of an emergency.

7.15.24.1 DISTANCE FROM THE WORKPLACE

MineARC Systems recommends that refuge chambers 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 pace, using 50% of the nominal duration of the SCSR. If it is assumed that workers are equipped with SCSRs of nominal 30-minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach safety.
This distance should be regarded as an absolute maximum because:

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

It should be noted that crawling is necessarily slower than moderate walking, and should be allowed for where applicable.

7.15.24.1.1.1 NOMINAL DURATION OF SCSR's

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 attempts to build a realistic and practical safety margin into the duration of SCSRs. Refer to appendix 11.

7.15.24.1.1.2 SAFETY OF LOCATION

7.15.24.1.1.2.1 EXPOSURE TO HAZARDS

Although the positioning of a refuge chamber is strongly governed by its accessibility for people in need of its protection, any potential susceptibility of its location to the hazards of rock fall, 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.

7.15.24.1.1.3 GROUND CONDITIONS

While it is recognised that it may be impossible to locate a refuge chamber excavation in an area free from normal rock mass 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, rock mass 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.

7.15.24.1.1.4 WATER

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.

7.15.25 CERTIFICATION AND MAINTENANCE

7.15.25.1 MAINTENANCE

For a refuge to fulfill 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 and due to the highly corrosive and abrasive atmosphere, refuge chambers should be inspected regularly and basic tests carried out (minimum four monthly) to ensure full functionality or as per the manufacturer’s recommendations.
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 refuge 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 will devolve to the engineering personnel, who should have access to the necessary information and equipment to undertake their duties.

7.15.25.1.1.1 COMMISSIONING

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 four month intervals.

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.

7.15.25.1.1.2 CERTIFICATION

MineARC Systems recommends that manufacturers have their refuge chamber designs certified and approved by the relevant regulatory authority before they may be deployed in underground mines. This is to ensure that refuge chambers being used within Australian mines can meet the specified performance criteria outlined in the relevant legislation. Manned testing should be completed to verify the life support capacity of the refuge chamber for a minimum of 1/3 of its rated duration, in stand- alone mode. All tests should be verified by an independent body to the satisfaction of the regulatory authority.

7.15.26 SUMMARY

During an emergency situation, the first priority for all underground personnel should be to find a place of safe refuge.

Fires, flooding, rock-falls, explosions and the release of smoke and other forms of toxic gas can block escape routes and leave personnel injured or simply overwhelmed.

Commonly, SCSR's only provide 30 minutes of breathable air supply, which studies have indicated equates to approximately 1500m travelling distance for a person of reasonable fitness, travelling at a reasonable speed, with no impediments. With many underground networks extending over a number of kilometres, travelling to a place of safe refuge during an emergency situation could prove to be a long and difficult journey, particularly for any personnel who have sustained injury and for those who may be assisting them

To counter this level of risk, it has been proposed here in this document that a network of emergency refuge chambers form an integral part of an underground mine's wider Emergency Response Plan (ERP). Refuge chambers should be designed to provide a safe and secure 'go-to' area for personnel to gather and await extraction in the event of an emergency.

A refuge chamber is a manufactured rigid vessel that is outfitted with supplies and equipment capable of sustaining life for a period of time (potentially days) while miners await rescue.
A suitable refuge chamber therefore has the following design requirements:

Breathable Air Supply:

Refuge chambers should be fitted with an external compressed air supply as its primary means of life-support. The external air supply should be sufficient to provide a minimum of 0.09m^3/min per person

The environment within a refuge chamber should therefore be maintained with oxygen content between acceptable limits. The acceptable range is between 19.5% and 23.5%

In the event of external air supply being lost a secondary oxygen supply should be installed to provide a minimum of 0.5L per person per minute.

Carbon dioxide removal systems shall be provided within the refuge chamber to maintain levels below 1%.

Carbon monoxide removal systems shall also be provided within the refuge chamber to maintain levels below 30ppm.

Cooling:

The acceptable cooling requirements for underground refuge chambers are defined in various international standards. All refuge chamber designs must take into account all internal heat loads such as people, lighting, heat generated by scrubbing systems, external environmental conditions, a minimum metabolic heat input of 117 watts per person, and minimum humidity of 1.5 litres of water per day per person.

Atmospheric Monitoring:

The refuge chamber must be equipped with independent internal environmental monitoring systems. In case of emergency, it must be able to monitor the O2, CO2 and CO in the refuge chamber.

Capacity and Safe Entrapment Duration:

The manufacturer should specify the nominal duration of the refuge chamber. The nominal duration means the minimum number of hours that a refuge chamber meets the performance criteria at its rated capacity at maximum operating conditions, e.g. ambient temperature.

The refuge chamber must supply the maximum number of occupants as specified by the manufacturer with breathable air, cooling and water for each occupant for a minimum of 36hours in stand-alone mode (without external air or power supply).

Structural Integrity:

The construction of a refuge chamber should allow for the circumstances in which it will be used. The chamber and its equipment mountings must be very robust.

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 maintained and monitored in good condition.

The system controlling the internal atmosphere should be capable of maintaining a positive pressure, nominally 200 Pa greater than the outside environment. This will prevent the ingress of toxic gases into the chamber. Over pressure protection should also be installed.

Refuge Chamber Positioning:

Although the positioning of a refuge chamber is strongly governed by its accessibility for personnel, its selected location is crucial for its ability to function correctly in the event of an emergency. If it is assumed that workers are equipped with SCSRs of nominal 30 minute (minimum) duration, at a rate of 30 litres per minute, then no-one should be expected to travel further than 750 m to reach a place of safe refuge.

This distance should be regarded as an absolute maximum.

Inspection and Maintenance:

For a refuge chamber to fulfill its primary purpose, it must be ready at all times for immediate, dependable use. This requires an effective and rigorous inspection and maintenance regime (four monthly minimum).

Certification:

MineARC Systems recommends that manufacturers have their refuge chamber designs certified to the relevant legislation to ensure that products being used within mines can meet the specified performance criteria.